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REGIONAL RESPONSE OF ODONATA TO RIVER SYSTEMS IMPACTED BY AND CLEARED OF INVASIVE ALIEN TREES

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Invasive alien organisms are a major threat to indigenous biodiversity. Invasive alien trees (IATs) are a component of this threat to South African odonates. IATs shade out the habitat of the sun-loving odonate species. A national programme to remove IATs from river systems has been initiated in South Africa. Results from widely-separated sites show that the impacts of IATs are the same in different physiognomic areas. In turn, removal of the IATs is beneficial to a range of species from narrow endemics to widespread generalists. Indications are that this nation-wide IAT-removal programme is beneficial across a wide geographical area, leading to rapid and significant odonate assemblage recovery. The IAT-removal programme must also consider removal of alien seedlings so as not to reverse the recovery programme.

INTRODUCTION

Invasive alien organisms are being recognized as the second-largest threat, after habitat loss, to biodiversity (WALKER & STEFFEN, 1999; WILCOVE et al., 1998) and a major cause of extinctions globally (CLAVERO & GARCIA-BERTHOU, 2005). Once alien plants are established they can spread and dominate a local ecosystem, outcompeting the local biota. South African river systems have been particularly heavily invaded resulting in a change from open, sunlit riparian zones to dark, closed canopy systems. This change also has a major influence on hydrology (LE MAITRE et al., 1996)

South African dragonflies are highly susceptible to the changes in canopy cover along rivers, with some Red Listed species threatened by these invasive alien trees (IATs) (SAMWAYS & TAYLOR, 2004), yet benefiting from removal of these IATs (SAMWAYS et al., 2005).

Several sites across South Africa fortuitously had been sampled prior to removal of the IATs at certain critical sites for rare and threatened species. This enabled a comparison of dragonfly assemblages before and after clearance of IATs. At some other sites, IATs had been removed from part of the river but not from other parts, enabling a spatial comparison. As these sites are along a curved transect around the southern and eastern part of the country, the farthest being about 2000 km apart, it provided an opportunity to compare widely separated sites to determine whether the local impacts are applicable to a regional scale. It also enabled a comparison of recovery of dragonfly assemblages with removal of IATs.

SITES

Site 1. – Franschhoek Pass (33°57'S, 19°12'E). This site was heavily invaded by *Acacia* spp., which was cleared in the late 1990s. The site is a perennial river (Du Toit's River) with adjacent braided pools. On removal of the invasive trees the pools were opened again to sunlight, and soon established a macrophyte community, including the water plant *Aponogeton* sp.

Site 2. – Lower Mitchell's Pass (33°24'S, 19°17'E). This site was heavily invaded by *Acacia* spp., which were cleared in the late 1990s – early 2000s. The site is a strong, perennial river (Breë River). On removal of the invasive trees, emergent rocks, which had been shaded for many years, were exposed to sunshine. The natural bank fynbos vegetation recovered remarkably quickly.

Site 3. – Upper Mitchell's Pass (33°25'S, 19°17'E). This site was heavily invaded by *Acacia* spp., which were cleared in 2001-2003. The site is a strong perennial river (Breë River) with grassy pools along parts of its banks. On removal of the invasive trees, emergent rocks and parts of the pools were exposed to sunshine. There was a rapid, profuse growth of natural grasses and sedges once the alien trees had been removed.

Site 4. – Uniondale (33°50'S, 22°26'E). This site was heavily invaded with *A. mearnsii*, which was removed along only part of the river in 2001. The site was a small perennial river (Doringrivier) of glides, riffles and pools. On removal of the alien trees, there was a profuse growth of lush grass, although with some bank erosion from loss of the tree canopy.

Site 5. – Joubertina (33°49'S, 23°50'E). This site was heavily invaded by *A. mearnsii*, which was removed along only part of the river in 2001. The site was a strong-flowing but small river (Nabooms River) of glides, riffles and pools. On removal of the alien trees, there was a rapid growth of grasses and forbs, although there was substantial bank erosion from rapid loss of the tree canopy.

Site 6. – Stutterheim (32°36'S, 27°25'E). This site was heavily invaded by *A. mearnsii*, but only along part of the river (Kubusi River), and so comparisons were made between heavily invaded and non-invaded sections of the river.

Site 7. – Pilgrim's Rest (24°53'S, 30°45'E). This site was in part heavily invaded by *A. mearnsii* and in part cleared about 1980. The river (Blyde River) is strong and of glides and riffles, with the cleared area supporting a margin of tall grass and forbs.

METHODS

Sampling was at each of two subsites (clear of invasive vegetation and invaded by alien trees). At sites 1, 2, 3, and 7 these subsites were the same physical area but separated in time. At sites 4, 5, and 6 sampling was at one time but in two areas (cleared or free of aliens and invaded). Site 1 was reassessed a third time as some rare endemics were discovered there.

At each subsite, ten 20 m lengths of the river were demarcated and all adult male Odonata individuals recorded with close-focus binoculars. Sampling was only on still, sunny days to ensure maximum apparency.

Site 1 was assessed on 1 February 1993 and again on 7 February 2000, and for a third time on 1

Table I
Species recorded throughout whole study at all sites

Code	Species	Site recorded
1	*Chlorolestes apricans* Wilmot, 1975 * RL	6c
2	*C. umbratus* Hagen in Sélys, 1862 *	1c*ab*
3	*C. tessellatus* (Burmeister, 1839) *	5c
4	*Elattoneura frenulata* (Hagen in Sélys, 1860)	1ic*ab*, 2ic, 3ic, 5c
5	*E. glauca* (Sélys, 1860)	1c*ab*, 2c, 3c, 5ic
6	*Allocnemis leucosticta* Sélys, 1863 *	1ic*ab*, 2c, 3ic,
7	*Metacnemis angusta* Sélys, 1863 * RL	1cb
8	*M. valida* (Hagen in Sélys, 1863) * RL	6c
9	*Ceriagrion glabrum* (Burmeister, 1839)	4c
10	*Pseudagrion draconis* Barnard, 1937 *	1ic*ab*, 2c, 3ic
11	*P. furcigerum* (Rambur, 1842) *	1c*ab*, 2ic, 3ic
12	*P. hageni hageni* Karsch, 1893 *	5ic, 6ic
13	*P. hageni tropicanum* Karsch, 1893	7ic
14	*P. kersteni* (Gerstäcker, 1869)	1ic*ab*, 2c, 3ic, 7ic
15	*P. massaicum* Sjöstedt, 1909	2c, 3c
16	*P. newtoni* Pinhey, 1962 * RL	7c
17	*P. salisburyense* Ris, 1921	6ic
18	*P. spernatum natalense* Sélys, 1881 *	5ic, 7ic
19	*Ischnura senegalensis* (Rambur, 1842)	1c*ab*, 2c, 3c, 4c, 5c, 6c,
20	*Proischnura polychromatica* (Barnard, 1937) * RL	1c*b*
21	*Africallagma glaucum* (Burmeister, 1839)	4c, 6c
22	*Agriocnemis falcifera* Pinhey, 1959 *	5c, 6c
23	*Platycypha caligata* (Sélys, 1853)	7ic
24	*Ceratogomphus pictus* Sélys, 1854	2ic
25	*C. triceraticus* Balinsky, 1963 * RL	2c
26	*Paragomphus cognatus* (Rambur, 1842)	1ic*ab*, 2ic, 3ic, 6ic, 7ic
27	*Aeshna minuscula* McLachlan, 1896	4c
28	*A. subpupillata* McLachlan, 1896 *	1ic*ab*, 2ic, 3ic, 7ic
29	*Anax speratus* Hagen, 1867	1c*ab*, 3c, 4c, 6c
30	*Orthetrum julia capicola* Kimmins, 1957 *	1ic*ab*, 2ic, 3ic, 4ic
31	*O. julia falsum* Longfield, 1955	7ic
32	*Nesciothemis farinosa* (Förster, 1898)	4ic
33	*Crocothemis erythraea* (Brullé, 1832)	1ic*ab*, 3c, 2c, 7ic
34	*C. sanguinolenta* (Burmeister, 1839)	1c*ab*, 2c, 3c, 7c
35	*Trithemis arteriosa* (Burmeister, 1839)	1ic*ab*, 2ic, 3ic, 4ic, 5ic, 6ic
36	*T. dorsalis* (Rambur, 1842)	4c
37	*T. furva* Karsch, 1899	1ic*ab*, 2ic, 3ic
38	*T. stictica* (Burmeister, 1839)	4ic
39	*Zygonyx natalensis* (Martin, 1900)	3c, 4ic

* = endemic taxon, RL = Red Listed, i = invaded, c = cleared, *a* = 1st sampling of cleared site one, *b* = 2nd sampling of cleared site one.

December 2003. Sites 2 and 3 were sampled on 1 February 1993 and again on 27 December 2001. Site 4 was sampled on 26 January 2002, site 5 on 27 January 2002, and site 6 on 28 January 2002. Site 7 was sampled on 3 January 2001.

Based on probability plots through the program Statistica©(Statsoft Inc. 2003) data were shown to be nonparametric. Therefore univariate statistics, in the form of Spearman's rank correlation coefficient, were used through the program Statistica to determine significance of correlations between dragonfly assemblage and invaded and cleared sites. Canonical Correspondence Analysis (CCA) was also performed with interspecies distances, biplot scaling and no transformation, with the program CANOCO (TER BRAAK & ŠMILAUER, 2003), to give a graphical summary of the data. CCA is robust and combines positive aspects of indirect gradient ordination with aspects of regression. It is also completely unhampered by high correlations among species or environmental variables. Testing the significance of the relation with environmental variables (invaded or cleared sites) was carried out by the Monte Carlo permutation test included in CANOCO.

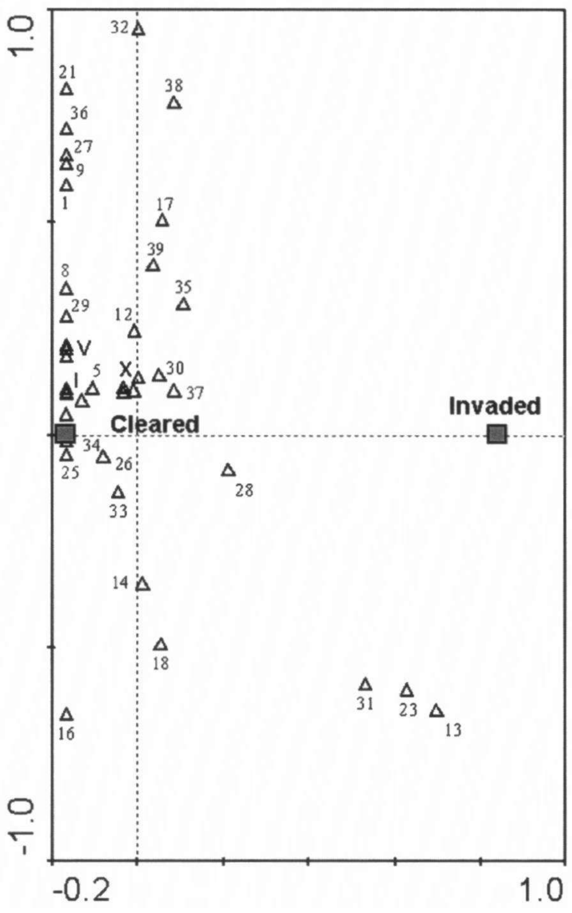

Fig. 1. Canonical Correspondence Analysis (CCA). Species are represented by (Δ). Nominal variables are represented by (□). X = 4, 6, 11, 24; – V = 3, 19, 22; – I = 2, 7, 10, 15, 20. For detailed description of species codes see Table I.

RESULTS

A total of 39 Odonata species were recorded across all seven sites in cleared or invaded situations (Tab. I). This includes many endemic and six Red Listed species (*Chlorolestes apricans, Metacnemis angusta, M. valida, Pseudagrion newtoni, Proischnura polychromatica, Ceratogomphus triceraticus*) which were only recorded in sites cleared of invasive plants. Species *C. apricans, C. umbratus, Elattoneura frenulata, E. glauca, Allocnemis leucosticta, Pseudagrion draconis, P. h. hageni, P. furcigerum, P. kersteni, P. newtoni, Ischnura senegalensis, Paragomphus cognatus, Anax speratus, Orthetrum julia capicola,* *Crocothemis erythraea*, *C. sanguinolenta*, *Trithemis furva* and *T. arteriosa* were all significantly negatively correlated for sites with invasive alien plants, while significantly positively correlated for sites cleared of alien invasive plants (R = - 0.455641, p = 0.000000 to R = - 163245, p = 0.045932 and R = + 0.455641, p = 0.000000 to R = + 163245, p = 0.045932). All other species were not significantly correlated. However, they were negatively correlated for invasive plants and positively correlated to sites cleared of invasive alien plants, with the exception of *P. hageni tropicanum*, *O. julia falsum*, and *Platycypha caligata*, which were positively correlated for sites with invasive alien plants and negatively correlated with cleared sites, but not significantly.

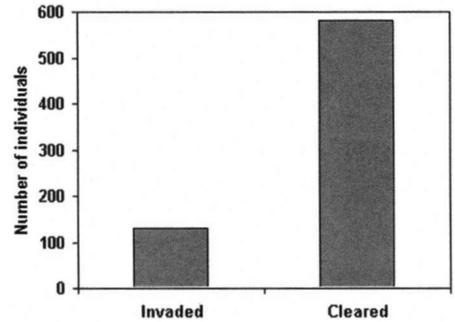

Fig. 2. Total number of individuals recorded over all sites, with the exception of the first survey of site one after it was cleared.

The graphical summary of data in the form of CCA (Fig.1) shows distinct separation of species composition from cleared sites and sites with invasive alien plants. A summary of eigenvalues and of the Monte Carlo permutation tests for the CCA ordination is given in Table II. The Monte Carlo tests resulted in axes which are significant ($p < 0.002$ with 499 permutations) and the environmental variables (invasive or cleared) explain species representation.

Invaded sites had a total of 130 individuals from 22 different species across all seven sites, whereas sites cleared of invasive plants had 581 individuals from 39 different species across all seven sites, not including the first survey of site one after it was cleared (Figs 1 and 2). Across all seven sites, there was noticeably more species and greater abundance in sites cleared of invasive plants than sites with invasive plants. Site one also shows greater number of species and individuals over time once invasive plants were removed.

Table II
Summary of eigenvalues and Monte Carlo test for CCA ordination

Axes	1	2	3	4	Total inertia
Eigenvalues	0.209	0.776	0.682	0.599	8.403
Species-environment correlations	0.628	0.000	0.000	0.000	
Cumulative % variance of species data	2.5	11.7	19.8	27.0	
Cumulative % variance of environmental data	100.0	0.0	0.0	0.0	
Monte Carlo test of significance	F-ratio	P-value			
All canonical axes (0.209)	3.138	0.0020			

DISCUSSION

The results here categorically show that IATs are a major threat to South African dragonflies over a wide geographical area. The dragonfly assemblages sampled were from different physiognomic areas yet the impact was similarly great across the geographical range.

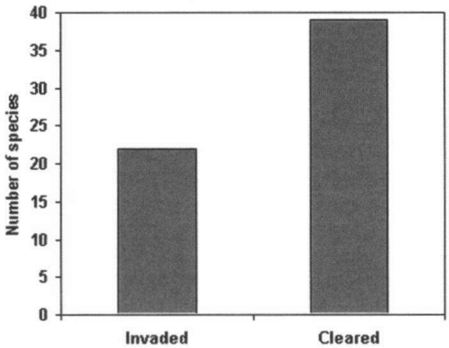

Fig. 3. Total number of species recorded over all sites, with the exception of the first survey of site one after it was cleared.

The impact of the IATs on the endemic and Red Listed South African odonate species has already been established (SAMWAYS & TAYLOR, 2004), and recovery of odonate populations when IATs are removed has been shown in two geographical areas, the Western Cape and Mpumalanga (SAMWAYS et al., 2005). The results here show that threats from IATs to the Eastern Cape endemics (*Chlorolestes apricans* and *Metacnemis valida*) are equally great and that removal of these IATs is likely to confer upon them a reprieve from probable extinction. This emphasizes the great value of the extensive national Working for Water Programme, dedicated to removal of IATs in water systems. The results to date illustrate a very positive effect on aquatic biodiversity.

Interestingly, this study showed that many common and widespread species were also impacted by IATs, and removal of this threat clearly benefited them. Thus the impact of the IATs is one of general biotic impoverishment and not just a threat to rare and specialist species. However, three taxa, *Pseudragion hageni tropicanum*, *Orthetrum julia falsum* and *Platycypha caligata* nevertheless benefited from IAT infestation, which provided shade and therefore suitable habitat for these taxa. The first two of these taxa are geographically widespread subspecies, yet their endemic counterparts, *P. h. hageni* and *O. julia capicola* were sensitive to IAT impact.

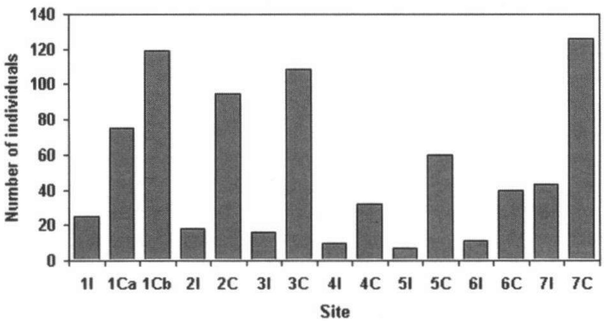

Fig. 4. Total number of individuals recorded across all sites. C = cleared sites; – I = sites with invasive plants.

The impoverishing effect of IATs and the odonate recovery after their removal, refers

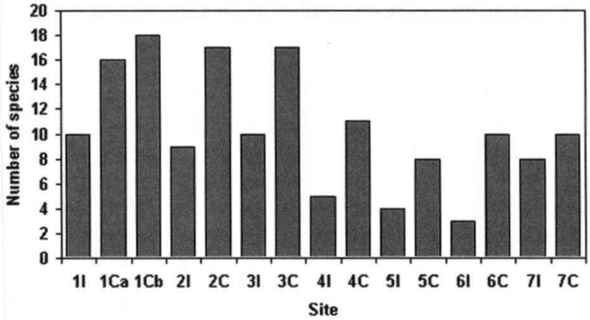

Fig. 5. Total number of species recorded across all sites. C = cleared sites; – I = sites with invasive plants.

to abundance as well as presence/absence of species. Overall, there were only 22% of the individuals in infested sites compared with natural and/or cleared sites, and only 56% of the species. Preliminary evidence from Site 1 indicates that recovery is not immediate but takes several years, as the natural vegetation, and presumably the natural water condition, first must recover.

The implications for management are categorial. IATs are a clear threat to both rare endemic as well as widespread odonate species, and that removal of IATs is a highly effective means of ensuring odonate assemblage recovery. Such removal must also consider follow up procedures that remove IAT seedling growth, so that natural vegetation, and thus natural odonate populations, recover.

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