Case history studies of the effects of vegetation succession and fire on the moth *Fraus simulans* (Lepidoptera, Hepialidae) and its food plant, the sedge *Ecdeiocolea monostachya* (Ecdeiocoleacea) in the Western Australian Wheatbelt: implications for retention of biodiversity

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Field observations of the effects of succession of vegetation, grazing by the moth *Fraus simulans* on the sedge *Ecdeiocolea monostachya* in a long unburnt area, the post-fire survival and regeneration of established tussocks and the survival of seedlings germinating in the first winter following burning are presented. There was considerable post-fire mortality of the established tussocks and in only one of the three areas burnt did any of the seedlings survive successive summer droughts. Surviving seedlings did not replace the tussocks killed by the burning. The possible effects of fire, drought and insect grazing on the biotic composition of small reserves are discussed. It is suggested that the information presented provides a basis for a formal decision process for risk assessment when managing reserves for retention of biodiversity and fire hazard reduction.

Key words: Fire, Sedge survival, Insect grazing, Plant succession, Summer drought, Decision making.

INTRODUCTION

RETENTION of biodiversity is now recognized as an important goal in conservation. Invertebrates, especially insects, make a significant contribution to this because of their variety, numbers and contribution to ecosystem processes. This paper reports on long-term observations which reveal interactions between fire, a herbivore (the moth *Fraus simulans*), its food plant (the sedge *Ecdeiocolea monostachya*) and their combined effects on the composition of the biota in reserves in the Wheatbelt of Western Australia. The observations have implications for reserve management because they challenge the common assumption of successful retention within reservations, as illustrated by the following citation: "Small vegetation remnants, such as those occurring throughout the Wheatbelt of southwestern Western Australia, for example, may be very useful in reflecting microcosms of the insect fauna formerly characteristic of the large surrounding areas cleared for grain production." (New 1987).

In 1967, B. Y. Main commenced observations on the trapdoor spider *Anidiops villosus* in Nature Reserve No. 17732 at North Bungulla (Main 1978). This involved frequent visits to the site and thus provided the opportunity to observe the effect of shrub maturation, senescence and regeneration on *F. simulans* and *E. monostachya*, which were both abundant in the reserve. After these observations commenced, the vegetation of the reserve was surveyed by Muir (1980) and this provided a framework within which to interpret the observations.

Some years later, the CSIRO Division of Wildlife and Rangelands Research (now CSIRO Wildlife and Ecology) proposed a research programme on "The ecological dynamics of remnant native vegetation" (CSIRO 1985), centred on an area North of Kellerberrin (31°38'S, 117°43'E) including Durokoppin Nature Reserve No. 22921 and East Yorkrakine Nature Reserve No. 23085. These sites lie within the areas described in detail by Saunders *et al.* (1993). Both reserves had been surveyed by Muir (1978, 1980). This detailed proposal ranged from the regional through landscape, ecosystem, community to the population level and had a management emphasis. At each level, a series of questions were posed which centred around patterns and processes. Perusal of the list of questions suggested that extension of observations on the moth and sedge at North Bungulla to the above reserves could be the basis of an approach to answering some of the conservation-related questions posed by CSIRO (1985), particularly: 1) the effect of clearing history on soil structure and vegetation, (p3); 2) the importance of herbivores and their effect on vegetation productivity and diversity (p5): 3) differences in plant community composition and structure due to disturbance (p6); the effects of fire on fauna and vegetation (p7); 5) the factors determining the ability of native fauna to reinvade disturbed areas and how such areas

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could be best restored (p7); 6) the growth rates of individuals (p8); 7) effects of fire on the long-term survival of animals (p9); and 8) the management objectives for remnants and the effects of present management practices on each of the levels (p9).

Management was to be by burning. It was decided to follow the fate of burnt sedge tussocks, the moth larvae or pupae in the tussocks, the regeneration of the tussocks and seedling sedge and moth recruitment in order to see whether the moth-sedge system could answer some of the above questions.

DESCRIPTION OF SITES

All sites are in kwongan (Beard 1976; Pate and Beard 1982), often locally referred to as sandplain or wodjil when the vegetation is dominated by *Acacia* thickets. Observations were made at four sites.

Site 1 — The North Bungulla Nature Reserve site (104 ha), about 10 km north of the townsite of Bungulla, situated about 12 km west of Kellerberrin in the central wheatbelt of Western Australia was a low sedge-dominated heath gently sloping down to the north, surrounded on all sides by tall shrubland dominated by *Allocasuarina acutivalvis, Grevillea paradoxa, Hakea multilineata* and wodjil (*Acacia stereophylla, A. neurophylla*), on sandy soils over lateritic clay. To the north (down slope), the study area was truncated by a wheatfield, to the east the shrubland lacked a ground cover of sedges, while the southern boundary was a large pit (no longer in use) from which laterite had been removed for road construction. Beyond the pit, tall wodjil extended up-slope to the southern boundary of the reserve which abutted on a wheat field. Wodjil bounded the study site to the west and extended to the adjacent road. The area had not been burnt since settlement.

Site 2 — This was one of two study sites in Durokoppin Nature Reserve, situated on high ground in the north-west tip dominated by *Allocasuarina campestris*, with *Acacia* and *Grevillea*, all growing on sandy laterite with a sedge understorey. This site was burned with a low intensity patchy fire in the late summer of 1988 (Atkins and Hobbs 1995).

Site 3 – This site consisted of two transects, one within an area that had been rolled, cleared and possibly cropped in 1938 or 1939 and then abandoned (D. Couper, pers. comm.) (site 3a). The boundaries of this area were readily recognized on aerial photographs. The vegetation was typical of kwongan on yellow sand, with *Xylomelum angustifolium* and the sedge *E. monostachya*. Site 3b was situated immediately to the north and outside the formerly cleared area. The western end of both transects ended in sandy laterite with *Dryandra* spp, while the eastern end was on similar sandy laterite dominated by *Allocasuarina* spp. The formerly cleared area was burned by CALM/CSIRO in a very intense experimental burn in the late summer of 1989 (Atkins and Hobbs 1995). The unrolled and uncleared area was not burned. Prior to this experimental burn, Levene's test showed the variance in frequency of tussocks per 25 m quadrat in the rolled and unrolled areas was not different. This suggested that regeneration after the earlier rolling and burning had restored the sedge to its former abundance.

Site 4 — The last area studied was the East Yorkrakine Nature Reserve, located between Bungulla and Durokoppin. This is a gently sloping, north facing sand-plain area dominated by *E. monostachya* and scattered shrubs of *Acacia* spp. The surveyed transect covered typical vegetation although cover was somewhat sparser than at other sites. The whole of the western end of the reserve was burnt in a CALM/CSIRO experimental burn in the summer of 1991.

METHODS

The sites to be burnt, the conditions under which the burning took place and the time of burning were determined by CSIRO/CALM. The precise timing of the burns was constrained by the need to take only acceptable risks associated with potentially dangerous fires at the end of a hot dry summer.

All localities to be burnt were surveyed by CSIRO and permanently marked on a cleared north-south aligned grid spaced at 100 m intervals. At site 1, sampling was along three, 2 m wide east-west aligned transects, situated in the northern, central and southern part of the sedge stand; each was 40 m long, and 50 m apart, 2 m wide (the extent of the sedge stand). At site 2, sampling was by means of 25 m long, 2 m wide, transects off-set from the grid points D 100, E 100, F 100, G 100 and H 100 (to avoid any effects of trampling caused by access along the cleared grid lines). At site 4, sampling was by means of 25 m long, 2 m wide transects off-set from grid points K 600, K 500, K 400, K 300, K 200 and K 100. Additionally, tussocks occurring in an *Acacia* thicket outside the transects were individually marked with stainless steel tags. At sites 3a and b, the transects were 750 m long, running east-west across a single vegetation type, and were originally designed to study the survival of the trapdoor spiders *Anidiops villosus* and *Cethegus* sp. Each transect (3a and b) was divided into thirty, 25 m sections, sampled over the whole transect at approximately 2 m width. Preliminary detailed sampling of 35 tussocks had shown no clear relationship between tussock diameter and numbers of moth larvae which, when abundant, could only be scored by effectively destroying the tussock. They were therefore simply scored as being attacked or not (see also under other observations). The occurrence of *Fraus* in areas outside those to be burnt, and thus lacking survey lines, was established by scoring 100 tussocks, defined as discrete growth forms, on a walked transect.

A tussock was deemed to have survived burning if, in the spring following the fire, it had regenerated a single culm. However, tussocks often failed to survive subsequent years. Burning often fragmented large tussocks and, unless they had been individually marked with fire resistant tags, it proved difficult to infer relationships to pre-burn tussocks. At site 4, tussocks within the area to be burnt were marked with numbered stainless steel discs.

BIOLOGY, LIFE HISTORY OF MOTH

The biology of *F. simulans* in Tasmania has been described by Hardy (1973). At the study sites, *F. simulans* emerge from the pupal case, usually during rain, in the first week of May. Mating follows, and the eggs are shed while the female walks, flutters, or flies above the soil (this study) (Common 1990). At the study sites, egg laying occurred after dark, usually when light rain was falling. Upon hatching, the larvae do not burrow, but spend the first few instars among plant debris and litter. During the current study, small larvae were found among webbed, charred vegetation fragments, small charcoal fragments and sand grains during winter. By late September-October the characteristic frass-covered vestibules to the burrows could be identified in sedge tussocks. Larvae leave the burrow to cut and feed on culms of the sedge. The debris from feeding is webbed to form a large spacious vestibule at the burrow entrance, thus indicating whether the tussock is attacked or not.

Burrows are silk lined in the upper part and may extend to a depth of 18.5 to 24 cm. Pupation takes place during late March or early April, pupae are mobile and can move vertically within the burrow. Pupal cases protrude from the vestibule after the imago emerges and can be readily scored. Pupae that survive fire, can be scored by the pupal cases which, remain at the burrow entrance.

RESULTS

Unburnt sites

Site 1 — Over the period of observation, the North Bungulla site was only disturbed by burrowing and grazing of rabbits, some superficial scraping by echidnas *Tachyglossus aculeatus* and by grazing kangaroos. During this period, the open stand of low shrubs and sedge was gradually reduced in size. First by the invasion of *Acacia* spp. and then by *Allocasuarina acutivalvis*. Drought and the grazing of rabbits eliminated many other seedlings; *Hakea* seedlings never survived the summer drought and *Grevillea* seedlings were either killed by grazing or drought. Seedlings of *E. monostachya* were never observed (see also Meney *et al.* 1994). In the summer of 1990/91, heavy grazing by grasshoppers *Chortoicetes terminifera* occurred with some mortality among seedlings of all species. The effect of all these events on the moth and sedge was difficult to quantify but, taken in conjunction with observations at Durokoppin, can be interpreted as follows; as the *Acacias* matured, they cast denser shade and, as a consequence, more moth larvae survived to graze, causing tussocks to die. Thus, the sedge ground cover and food for the moth was removed. No sedge seedlings were observed (see Meney *et al.* 1994). By May 1993, in a transect across an area which initially (1967) lacked shrubs and so defined the northern limits of the sedge stand, shrubs were assessed as follows:– *Acacia*, alive 8, all mature or senescent (collapsed); dead 13; thus leaving the area open to invasion by the aggressive aerially dispersed native *Allocasuariana acutivalvis* of which there were 11 more than 2 m high, but less than full size, which had flowered or bore fruits at the time; additionally along the transect there were six young *A. acutivalvis* (50 cm to <2 m tall). The outcome of such an invasion is that the litter of fallen *A. acutivalvis* branchlets smothers all vegetation, even in sites formerly dominated solely by sedge tussocks. By July 1997, all *Acacias* at this locality had died and collapsed. In October 1995, the southern, up-slope transect at North Bungulla, which initially had no tall shrubs, was being invaded by *A. acutivalvis,* of which there were 17 plants (three mature >3 m and with flowers or fruits and 14 immature (50 cm or taller)). Thus, on a time scale of decades, not only is the structure and composition changing, but at local scales biodiversity is being reduced. Interestingly, at this time, the pit which, shortly after the observation began, had been ripped as a rehabilitation measure, was being invaded by seedlings of *A. acutivalvis.* From the above observations, it seems likely that *A. acutivalvis* will dominate the final plant assemblage.

Site 3b — except for the senescence of some tall *Xylomelum* and *Acacia* shubs, and the invasion of some *Allocasuarina acutivalvis,* the site remained little altered over the period of observation.

Other sites — Sites 1 and 3b did not represent all the unburnt topographic situations where the moth attacked tussocks. On north facing upper slopes of topographic rises, which lacked shrubs, no tussocks were attacked. On slopes with western aspect, fewer of tussocks were attacked on the upper slopes compared with the lower slopes (χ^2, 283.19, df 1p << .001). At the bottom of the slope, in an area subject to flooding by runoff from an adjacent wheatfield, there were significantly fewer tussocks attacked than in the adjacent non-flooding area (χ^2, 26.42, df 1p << .001).

Similar vegetation east and west of the Kellerberrin-Trayning road allowed the comparison of *Fraus* abundance in areas cleared in 1938 or 1939 (east of road) and uncleared (west of road). Fewer tussocks were attacked by the moth in the formerly cleared area (Fisher's Exact Test: χ^2, 32.265 df 1p << .001). At sites 3a (formerly cleared) and 3b (never cleared), the abundance of tussocks was not different (2 tailed t-test ns). The above observations suggest that the soil disturbance associated with clearing may in some way have reduced the suitability of the habitat for the moth.

Despite these apparent differences, any clear-cut interpretation was confounded because all sites wherever located on the topography, appeared to be more frequently and more heavily attacked where shade was provided by the canopy of any taller vegetation that was present. Moreover, monitoring at North Bungulla along fixed transects showed that tussocks attacked on the upper slopes varied markedly from year to year. In 1991 and 1992 none of the tussocks in these transects had moth larvae. Clearly site and season have an influence. A further complication had been revealed in May 1989, when a careful dissection of 46 burrows with apparently unweathered frass in 18 tussocks was made immediately following the emergence of the moths. The results were as follows:- empty pupal cases (successful emergence of moths) 9; pupae still in burrow 10; pupae dead, shrivelled in burrow 2; burrows with no larvae or pupae and no obvious remains 25. On other occasions, discoloured larvae were seen in vestibules. Taken together, these observations are consistent with an interpretation that the larvae and pupae are affected by a pathogen such as the baculoviruses that control *Wiseana* spp. (Lepidoptera:Hepialidae) which are pasture pests in New Zealand (Crawford and Kalmakoff 1977).

Burnt sites

Site 2 — At the end of the spring following the fire of the summer of 1988, approximately 80% of the tussocks between 0 and 100 m on transects E, F, G, H, were judged to have survived. A year later, that is, the end of the second spring following the experimental burn, only 138 of 366 pre-burn tussocks survived. The presence of pupal cases indicated that, of 168 burnt tussocks in the four 25 m transects offset at E 100, F 100, G 100, H 100, moths emerged as follows; none from 112, 2 from each of 34, 3 from each of 14 and 3, 4, and 5, from each of 2, 3 and 3 tussocks respectively. There was good germination of the sedge in the first winter following the fire, but none subsequently. In the four transects that had been burnt, 99 seedlings were individually marked and then followed for survival until July 1991. The numbers surviving were as follows: after the first summer, 67, second summer, 64 and third very hot summer, with heavy grazing by grasshoppers, 21. Many of the survivors were only a few centimetres tall, having been eaten by grasshoppers. Sampling was now becoming very destructive to the regenerating shrubs and ceased until October 1997, by which time surviving marked seedlings were very rare. However, seven seedlings were located and these had culms ranging in length from 32 to 56 cm and in number from 4 to 13 (mean 7). Of the seven seedlings, four had been attacked by the moth (one by two larvae), but only one moth had emerged from a seedling on which 12 culms had been consumed by the larva leaving four culms each about 32 cm long. Thus, at this site, it takes nine years growth and 12 culms to support one larvae to emergence. At 11 years post germination, no seedling had flowered.

Site 3a – This site was burnt in the late summer of 1989. This was a very hot "clean" burn with almost complete destruction of litter, debris and standing shrubs, leaving only a bare mineral soil bed. Using the criterion of a single culm as indicating survival at 21 November 1989, that is the first spring after the burn, 37 of 285 tussocks had been killed by the fire. When scored on 21 October 1997, detailed comparisons could not be made because of fragmentation of tussocks and vigorous regeneration of shrubs. However, the impression was that the numbers of tussocks surviving were consistent with the level of post-burning mortality observed among individually marked tussocks among *Acacias* at site 4. Germination of seeds of shrubs and their seedling establishment was good. However, this was not the case with the sedge; along the established transect in the burnt area only four seedlings were counted and none survived the summer of 1990. In subsequent winters, no further germination was observed. In May, no pupal cases were observed in the burnt tussocks. The first pupal cases from emerged moths were seen in June 1992 and interpreted as successful re-invasion of the burnt area by the moth.

Site 4 — At this site the fuel load was less than at 3a (R. J. Hobbs, unpubl. data). It was burned with a very hot fire in the late summer of 1991. Observations of the 31 marked tussocks with active moth larvae within the *Acacia* copse showed 24 tussocks survived to the next spring and none were attacked by moth larvae. However, by June of 1993, only nine tussocks survived, seven being attacked by the larvae. From these, one moth emerged. By May 1998, there had been no mortality among the tussocks in the quadrats at K 100 to K 600, but none had flowered or set seed. The quadrats used for studying the survival of moths were used to follow seedling survival. As shown in Table 1, a total of 800 seedlings in the six quadrats were followed from the spring of 1991 to May 1998 when no seedlings survived.

Table 1. Survival of seedlings of the sedge *Ecdeiocolea monostachya* which germinated following the fire of late summer 1991.

Year	K 600	K 500	K 400	K 300	K 200	K 100	Total
1991	135	40	63	131	107	324	800
1992	39	15	22	49	21	45	191
1993	28	15	21	42	29*	30	165
1997	1	0	0	0	5	1	7

*eight seedlings classified as dead in 1992 had resprouted the following year.

After the initial germination at these sites, no further germination or sedge seedlings were observed. Survival of moth larvae or pupae was assessed in the quadrats at surveyed grid intercepts K 100 to K 600. A total of 247 tussocks were scored and no pupal cases were observed. In the *Acacia* copse prior to the fire, a total of 31 tussocks with larvae were individually marked as follows: 22 had one larva, five had two larvae, three each had three larvae, and one had eight larvae. None of these larvae survived to emerge as moths. The first frass from moth larvae was observed in October 1992 within regenerating tussocks in the *Acacia* copse, suggesting re-invasion by the moth. In May 1993, one pupal case indicated the emergence of an adult. In subsequent years frass and pupal cases were common.

DISCUSSION

From the foregoing, it is apparent that the following are the answers to the questions posed at the beginning of the study (CSIRO 1985) and listed in the introduction.

1. The effect of clearing history on soil structure and vegetation

At sites east and west of the Kellerberrin-Trayning road (cleared and uncleared respectively), there were fewer tussocks attacked in the formerly cleared but naturally revegetated land. Possibly this may be interpreted as changes in soil structure leading to higher soil temperatures and drier soils and suggests that vegetation regeneration may be less sensitive to disturbance than *Fraus*.

2. The importance of herbivores and their effects on vegetation, productivity and diversity

At North Bungulla, the sedge and the moth are both favoured by the shade provided by *Acacia* thickets. Ultimately, the sedge goes to extinction as a consequence of grazing by the moth, which also becomes locally extinct. As the canopy of the acacias thins with maturity, the stands are invaded by *Allocasuarina acutivalvis* which finally forms a pure stand with loss of ground cover plants which are intolerant of the thick litter of fallen branchlets of *Casuarina*. At the casual observational level, the moth appears to be an insignificant herbivore, yet under some circumstances (e.g., as at North Bungulla) it can, over decades, contribute significantly to patchiness of ground cover and ultimately invasion of the site by *A. acutivalvis*.

3. Differences in plant community composition and structure following disturbance

At site 2, seedlings survived summer heat and water stress in the shade provided by still standing burnt shrubs. Burning at site 3a led to low germination of the sedge and no seedlings survived the first summer. At site 4 there was good germination of the sedge, but no seedlings recruited to the population.

4. The effects of fire on fauna and vegetation

In the north-west tip of Durokoppin (site 2), the burn was of variable intensity and patchily distributed, resulting in some patches of shrubs being completely destroyed, while others were merely scorched. Initially, only the severely burnt sedge tussocks were killed, but deaths continued into subsequent years. Sedge seedlings survived and after nine years could support moth larvae to maturity. The survival and growth of seedlings and the support of larvae is, to some extent, due to the amelioration of the hot summer conditions by the shade cast by the dead, but still standing, burnt shrubs. At this site, seedling recruitment did not counteract fire-induced mortality of established tussocks.

An intense hot fire over an extensive area with a high fuel load (site 3a) saw few seedlings germinate and none survived. Tussocks survived the fire, but a high proportion died in later years. Superficially, the area burnt gives an impression of excellent recovery of the vegetation.

At site 4, a hot fire burnt an area with only a moderate fuel load. Seed germination was good. Mortality of sedge seedlings was very high in the shadeless seed bed so that by May 1998 none survived. In contrast, there were patches where shrub regeneration and survival was high. It is clear that the conditions on the day of the burn, the fuel load, the intensity and patchiness of the fire, as well as subsequent environmental conditions (e.g., intensity of summer drought,) determines the success of regeneration of the tussocks. The observations indicate that recruitment of sedge seedlings are also sensitive to summer drought and that tussocks killed by the fire are not being replaced.

5. Factors determining the ability of native fauna to re-invade disturbed areas and how such areas could be best restored

It appears likely that a fire before pupation may destroy food necessary to complete larval growth. On the other hand, a burn soon after pupation may cause no pupal mortality, while one shortly before emergence when the pupae are near the burrow entrance is likely to cause high mortality. It is unclear whether after a hot clean burn, there will be left sufficient food or shelter for young larvae to survive. Thus, persistence of the moth-sedge association will depend on reinvasion by the moth of regenerating tussocks, which the above observations suggest may take at least two years, or seedlings which may be in excess of 10 years before flowering and seed set.

6. Growth rates of individuals

It is clear that apart from the risks associated with seedling establishment, it takes a minimum of 9–10 years under favourable conditions at this site before a seedling can support a moth larvae to maturity. In harsher conditions, such as following an intense fire, with no standing dead shrubs (e.g., site 4) the time is likely to be much longer.

7. Effects of fire on long-term survival of animals

The effects of an earlier episode of clearing (site 3a) was insignificant when measured by tussock density, but significant when judged by the abundance of moth larvae. Moreover, while the immediate post fire effects on vegetation were not remarkable, the mortality of established tussocks on formerly cleared land was subsequently very high. This, coupled with the present absence of regeneration of sedge seedlings, suggests that another fire within decades will lead to significant changes in the ecosystem and the sedge could become locally extinct.

8. The management objectives for remnants and the effect on present management

Overall, the findings suggest that hot fires are likely to be inimical to efforts at restoring or rehabilitating kwongan with *Ecdeiocolea* and *Fraus*. The findings from the patchy fire at site 2 suggest that the ecosystems there were resilient to this level and intensity of disturbance. However, while fires with such characteristics may not lead to loss of species, they may not contribute significantly to fuel reduction over a long period and thus reduce fire hazard. On the other hand, intense fires, while reducing fuel load for a longer period may not only put sensitive species at risk, but also favour invasion by exotics in disturbed areas, such as result from animal diggings, during the immediate post fire period of regeneration. But leaving an area unburnt does not ensure maintenance of biotic assembles, as shown in the North Bungulla Nature Reserve where grazing by rabbits prevented the establishment of shrub and tree seedlings and grazing by *Fraus* larvae killed established sedge tussocks where they were shaded by *Acacias*.

The matter of adequate reserve management, especially hazard reduction burning, is complicated by the perceptions and beliefs of adjacent land holders and in this regard I have heard the following comments which perhaps reflect common views: "fires always start in the scrub of reserves", "the bush always looks so good and green when regenerating after burning", and "it's easy to get away with burning the bush. Just light it when thunderstorms are about". Such views may obtain a wider currency if shortages in funding lead to a perception that reserves are being neglected.

9. Management objectives for remnants and the effect of present management on each of the levels

The foregoing results suggest that the retention of biodiversity will be neither simple nor easy to achieve. This is especially so if the present distribution and abundance of the sedge and moth are to be maintained. Small, rather than large scale, manipulation would seem appropriate until there is a better knowledge base particularly relating to life history traits and drought responses.

General conservation issues

This study has moved beyond the area and time scales normally handled in experiments. The findings are on a scale relevant to reserve management and the maintenance of simple biotic interrelationships, such as the sedge and the moth, or of floral composition, following the invasion and dominance of *A. acutivalvis*.

In an earlier paper, I have remarked on the apparent recent development of the invasive trait in *Allocasuarina* (Main 1992) and attributed the success as an invader to the absence of the

Tammar Wallaby *Macropus eugenii*. McFarlane *et al.* (1992) and George *et al.* (1995) have drawn attention to the rapidly rising water tables in the Wheatbelt and this may be an additional factor favouring the invasive spread of *Allocasuarina*. However, in North Bungulla the interpretation is confounded by the absence of burning.

The genus *Fraus* is regarded as one of the "primitive" hepialids (Nielsen and Kristensen 1989) and so, while common, it has intrinsic worth as an object for conservation. However, the biological interactions and physical impacts outlined above suggests that commonness is not, by itself, sufficient to ensure persistence. This example thus offers a timely warning against adopting a complacent attitude that common elements of the biota are safe. The risks faced by them will only become apparent when life history and other biological requirements are known. Indeed the effects of presence or absence of a canopy on the variability and abundance of moth larvae; whether the larvae are indeed infected with a pathogen; and the between season and site variation in larval survival needs to be pursued.

Another moth associated with *Ecdeiocolea* in the study area is the Sun Moth *Synemon catocoloides* (Family Castniidae). This family is of biogeographic interest, with one genus in south-east Asia, one genus in Australia and the principal elements in Central and South America (Common 1990); thus it may represent an old Gondwanan faunal element and so have high conservation value. Sun Moths are much rarer than *Fraus*, judging from the few moths seen flying close to the ground among sedge tussocks in November. The life cycle possibly spans two years, and thus is not comparable with the annual cycle of *Fraus*. The entrance to the silk lined tunnel of late stage Sun Moth larvae extends above the soil surface. These extensions are referred to by Common (1990) as chimneys and are readily observed. Nevertheless, both are dependent on the sedge and the sun moths are likely to be as susceptible as *Fraus* to the effect of fire. Neither the Sun Moth nor chimneys made by them were observed on the formerly cleared area (site 3a). The decline in sedge tussocks following the fire argues against the likely persistence of Sun Moths. In eastern Australia the Sun Moth *S. plana* is threatened through the loss of native grassland (Anon 1993). *Ecdeiocolea* is likely to be the food plant of *S. catocoloides* and, being widespread, the sedge is clearly an analogue of the once widespread grasslands favoured by *S. plana*. Since the sedge is at risk from wildfires, it follows that the sun moth is a potential candidate for endangerment.

In a sense, the study has been merely natural history, yet the findings have important connotations for management. It is apparent that in areas 3a and 4, two components of the biota, the moth *Fraus* and the sedge *Ecdeiocolea* have been severely reduced in numbers. Should subsequent burns occur before tussocks surviving fire, or seedlings, set seed, the prospect of losing the two species element of the ecosystem is very high because of the attrition of the numbers of sedge tussocks by fire, the sensitivity of sedge seedlings to summer drought and the time required for seedlings to reach a size which will support moth larvae or reproduce. These findings are scale-related and are likely to be most significant in small reserves and in local areas. It is clear that analysis of problems associated with retention of the sedge/moth association tend towards case-studies and are unlikely to yield widely applicable statistically validated patterns because sites differ in burning histories, post-burning regeneration and drought which may be modified by the topographic location, clearing in the past, and the effectiveness of shady refuges favouring moth survival with consequent increased grazing pressure on the sedge. On the other hand the problems may not arise because:-

1. It may be possible to have cool patchy burns, as at site 2. To what extent burning can be scheduled for cool weather rather than a planned more or less fixed or scheduled calendar date will be difficult. Moreover, funding for this sort of management on all nature reserves would be very expensive and thus unlikely; or
2. It may be that a sequence of wet years with summer rainfall from thunder storms or decaying tropical cyclones would maintain growth of seedling sedge plants during the early summers following germination after fire. These conditions are unpredictable and the reality is that fire from lightning strikes, accident or arson are much more likely. Thus, there is the prospect of the loss of the moth and the sedge from the local system.

The above findings illustrate what may be a common problem when managing reserves for retention of biodiversity, namely that inter-dependent biotic elements, for example, a herbivore (*Fraus* with an annual life cycle, poor dispersal and possibly affected by a pathogen) and its food plant (*Ecdeiocolea* which is long-lived, dependent on fire for regeneration, having no persistent soil seed bank (see also Meney *et al.* 1994) and currently, poor survival of seedlings), are so disparate in terms of biology, dispersal powers and ability to recruit that retention of the moth and the sedge in a moving mosaic of sedges of all ages colonized by the mobile moths will be very difficult to achieve, especially in small reserves.

The findings reported flesh out the biological problems associated with reserve location within the landscape as set out by Main (1987). In particular, the moth and the sedge occur at difference densities and respond differently to burning, depending on whether located on topographic highs, drainage lines, beneath a higher shrub canopy or on formerly cleared land. The difficulties alluded to above suggest that formal assessment of the risk to biodiversity associated with hazard reduction burns should precede implementation of burning by management. A method appropriate for such an assessment of risks was proposed by Main (1992). The natural history of the moth, its food plant, their responses to fire and the effects of summer drought on regeneration and establishment of sedge seedlings in seasons affected by drought associated with an El Niño-Southern Oscillation (ENSO) event indicate the factors which should be taken into account when making such an assessment.

Finally it needs to be emphasized that being serious about conserving biodiversity involves considering more than just plants and vertebrates. Moreover, even simple systems are complex.

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