Seasonal activity of hexapods in woodland and forest leaf litter in the south-west of Western Australia

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Abstract

Invertebrates were collected in pitfall traps monthly between March 1976 and February 1977 at 3 localities in the south-west of Western Australia, namely Perth (Reabold Hill), Dwellingup and Manjimup. The Collembola and Insecta are treated here.

Herbivore diversity was high in spring, summer and early autumn at Perth, and in summer and early autumn at Manjimup; although diversity fluctuated less with season at Dwellingup it was lower in the winter. Predator and parasite diversity was highest in late autumn and early spring at Perth and Manjimup, but seasonal trends again were less obvious at Dwellingup. The numbers of individuals and species of ant were low in winter, increased in spring and summer, and decreased again towards the end of autumn at Perth and Dwellingup. At Manjimup, the seasonal activity of ants was less marked although more species were active in summer. Most Collembola species were trapped in Perth in winter, and in autumn, winter and spring at Dwellingup; but the Manjimup data are insufficient for interpreting.

The data from this paper are combined with those of Koch and Majer (1980) on non-hexapod groups collected at the same time. The 3 sites had different phenological patterns and this was particularly marked at Manjimup where temperatures are lower and relative humidities higher.

Introduction

In a previous paper, we (Koch and Majer 1980) reported on the phenology (seasonal-succession) of non-hexapod invertebrates collected in pitfall traps operated at monthly intervals for 1 year (between March 1976 and February 1977) at 3 sites in the south-west of Western Australia. These sites and the numbers of years from the last fire to the start of the study were: Perth (Reabold Hill) 5 years, Dwellingup 8 years, Manjimup 3 years. Site data are summarised in Koch and Majer (1980). The present paper continues recording the investigations by dealing with the hexapod component of the catches.

In both papers, the extent of a feeding activity, such as predation, is judged by the number of species trapped per month. As in our previous paper, we recognise the limitations of pitfall trapping for sampling. The numbers of a species caught depend upon its abundance and activity.

In treating the non-hexapod component of the epigaeic fauna, we (Koch and Majer 1980) compared the decomposers with the predators and concluded that the species richness of both these categories was reduced for at least 3 years after fire. We also found that the activity/abundance of decomposers, and presumably the amount of decomposition, was higher at Perth and Dwellingup during the wetter months but was more closely associated with the warmer months at Manjimup. Predators, active throughout the year, showed a decrease in activity during the cool moist months at Dwellingup and Manjimup.

The aims of this study are to record the species in the study areas, to examine the relationship between species richness and climate and to describe seasonality of the different taxa and types of feeding taking place on the forest or woodland floor. Finally, the data from the paper are combined with those on non-hexapods to attempt to summarise seasonality of epigaeic invertebrate activity.

Methods

The sites have been described and climatic data figured in Koch and Majer (1980). Temperature and rainfall records are directly comparable between sites. Relative humidity records, however, are for 0900 hours at Perth and Dwellingup and 0800 hours at Manjimup. The consistently higher relative humidity values at Manjimup partly result from the lower temperatures at the time of recording although some records available for 0900 hours at Manjimup suggest that humidity is generally higher there.

The samples were collected in pitfall traps spaced 3 m apart in a 6 by 6 trap grid. Each trap was a tube (15 cm long and 1.8 cm internal diameter) containing a 3 mL mixture of alcohol/glycerol (70/30 v/v) and sunk vertically at ground level (Majer 1978). Traps were operated for a 7-day period every 4 weeks between March 1976 and February 1977. The specimens were sorted into species,

some sent to specialists, and representatives lodged in the Western Australian Museum.

The various species encountered in the present paper have been tentatively regarded as belonging to 6 feeding categories: decomposers, herbivores, omnivores, scavengers, predators and parasites. The numbers of individuals in these feeding categories are, where possible, analysed in relation to climatic conditions.

Results

The numbers of specimens of each species collected during each trapping week over the study period are shown in Table 1. The collembolans (springtails) and the ants are dominant in terms of numbers of individuals and species and are treated separately. Because sampling was performed at 4-weekly intervals, the sampling dates did not necessarily coincide with the calendar months. Therefore for clarity, the data have been centralised under each calendar month in Table 1. In the few instances where 2 samples were obtained in a month the mean number is given. In Table 1, the 6 feeding categories are given; however most of the species are herbivores, predators or parasites.

The Collembola species collected at each site are shown in Table 2. It is not possible to give monthly counts because these minute, delicate creatures rapidly decompose when the liquid in their traps becomes

diluted by rain. Owing to such decomposition it would be more likely for a particular species to pass unrecognised in a monthly rather than in a seasonal sample count. Therefore seasonal totals of the species at Perth and Dwellingup are given (Table 3). The census of Collembola species at Manjimup is a gross underestimate, perhaps due to deterioration of material in the traps and laboratory. The Manjimup Collembola data are therefore not examined for seasonality.

The monthly totals and overall counts of individuals and species of ants trapped at each site are shown in Table 4. The determinations and individual species counts will be presented in a separate paper on the ants.

The decomposer, omnivore, or scavenger components of the fauna in Table 1 are insufficient for species richness between sites or seasonal trends to be compared. The total numbers of species and individuals of the more frequently trapped categories (the herbivores, and predators and parasites) are shown for each site in Table 5. The data on predators and parasites are pooled since both are consumers of living animal material. Table 5 also shows the total numbers of species of herbivores and of predators/parasites trapped each month. The collembolans are treated as a group associated with decomposition of organic material although their feeding habits are diverse. Ants are treated as a

Table 1

The number of individuals of each species of hexapods collected per month in pitfall traps at three sites in the south-west of Western Australia from March 1976 to February 1977

		1976										1977	
		M	A	M	J	J	A	S	O	N	D	J	F
COLLEMBOLA													
(See Tables 3 and 4)													
BLATTODEA													
Blaberidae													
Calolampra (herb., omniv.)†	P*	0	0	0	1	0	0	0	0	1	0	0	0
	D	0	0	1	0	1	0	0	0	0	0	0	0
	M	3	7	12	19	1	0	3	0	0	0	0	2
Laxta (herb., omniv.)	M	0	0	0	0	0	0	0	0	1	0	0	0
Blattidae													
Polyzosteriinae (herb., omniv.)	P	0	1	0	0	0	0	0	0	0	1	1	0
Blattidae (b) (herb., omniv.)	D	0	0	0	0	0	0	0	1	0	0	1	0
Blattidae (c) (herb., omniv.)	P	0	0	0	0	1	0	0	1	0	0	0	0
	D	0	0	8	3	0	0	0	3	0	0	0	0
MANTODEA													
Amorphoscelidae													
Paraoxypilinae (a) (pred)	P	2	0	0	0	0	0	0	0	0	0	0	0
Paraoxypilinae (b) (pred.)	D	0	0	0	0	0	0	0	0	1	0	1	0
DERMAPTERA													
2 or 3 spp. (pred.)	P	171	86	46	30	44	17	78	77	289	247	714	423
	D	68	67	60	63	7	0	3	57	59	37	103	56
	M	12	8	11	5	2	3	3	16	17	21	84	27
ORTHOPTERA													
Stenopelmatidae													
Onosandrus (omniv.)	P	0	0	0	3	2	1	0	0	0	5	3	0
	D	0	0	12	0	5	3	5	5	4	4	0	0
Gryllidae (a) (herb.)	P	1	3	1	0	5	3	0	0	0	0	20	13
	D	0	0	3	0	0	1	0	0	0	4	0	0
	M	0	2	3	2	0	0	0	0	0	0	2	0
Gryllidae (b) (herb.)	D	3	0	0	0	0	0	0	0	0	0	0	1
Gryllotalpidae (herb.)	P	0	0	0	1	0	0	0	0	0	0	0	0
Acrididae													
Phaulacridium vittatum (herb.)	P	0	1	0	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	1	0	0
	M	0	0	0	0	0	0	0	0	0	0	0	2

Table I continued

		1976									1977		
		M	A	M	J	J	A	S	O	N	D	J	F
HEMIPTERA													
Fulgoroidea (herb.)	P	0	0	0	0	1	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	1	0	1	0	0
Cicadellidae													
Ledrinae (herb.)	P	0	1	0	0	0	0	0	0	0	0	0	0
	D	0	1	0	0	0	0	0	0	0	0	0	0
	M	0	0	0	0	0	0	0	0	0	0	0	1
Alydidae													
Leptocorisa (herb.)	P	5	1	0	0	0	0	0	0	0	0	0	1
	M	0	0	0	0	0	1	0	0	0	0	0	4
Reduviidae (pred.)	P	0	1	4	0	0	0	1	2	4	1	1	0
	M	0	0	1	0	0	0	0	0	0	0	0	0
Lygaeidae (herb.)	D	0	1	0	0	1	0	0	0	0	0	0	0
Cydnidae													
Cydnus (herb.)	P	4	1	2	0	0	0	1	4	14	14	4	4
	D	0	0	0	0	0	0	0	0	0	1	0	0
	M	0	0	0	0	0	0	0	0	0	1	1	4
Gelastocoridae													
Nerthra stali (pred.)	D	0	0	0	0	0	0	0	2	0	0	0	0
	M	0	0	0	0	0	0	0	0	0	0	0	4
Hemiptera Nymph (herb.)	D	0	0	0	0	1	0	0	0	0	0	0	0
THYSANOPTERA (dec.)	P	0	0	0	0	1	1	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	0	1	0
COLEOPTERA													
Carabidae													
Broscinae													
Gnathoxys crassipes (pred.)	P	5	1	1	0	0	0	0	51	1	6	5	4
Promecoderus (pred.)	P	2	0	56	71	45	24	15	5	54	6	0	0
	D	13	5	12	0	1	3	0	0	7	14	8	0
	M	11	3	5	6	0	0	2	2	8	19	9	3
Scaritinae													
Scaraphites lucidus (pred.)	P	0	0	0	1	0	0	3	5	1	3	0	0
Psydrinae													
Neonomius (pred.)	D	0	0	0	0	1	0	0	0	1	0	0	0
Pterostichinae													
Simodontus (pred.)	P	16	61	10	16	7	4	2	0	15	0	1	0
	D	0	1	1	0	1	0	0	0	1	0	0	0
	M	4	2	11	6	5	2	5	2	0	0	3	1
Carabidae Larva (pred.)	P	0	0	0	10	23	8	2	0	1	0	0	0
	D	0	0	0	4	2	3	0	0	0	0	0	0
	M	0	0	1	0	0	0	0	2	0	0	0	0
Staphylinidae													
Staphylinae													
Quedius (pred.)	D	0	0	3	1	0	0	1	1	0	0	0	0
	M	0	0	26	2	2	0	2	0	0	2	0	0
Staphylinidae (b) (pred.)	D	0	0	0	0	0	0	1	0	0	0	0	0
Oxytelinae													
Anotylus (pred.)	P	0	0	0	1	0	1	2	0	0	0	1	0
	D	0	0	0	52	4	7	51	94	3	0	0	0
	M	0	0	1	0	0	0	0	13	3	0	0	0
Aleocharinae (pred.)	P	0	0	1	1	0	0	3	0	0	0	0	0
	D	102	24	11	20	0	0	27	4	6	2	29	64
	M	0	0	0	0	0	0	0	3	5	0	0	0
Staphylinidae Larva (pred.)	P	0	0	0	0	0	1	0	0	1	0	0	0
	D	0	0	7	0	0	0	0	0	0	0	0	0
Pselaphidae (pred.)	P	1	1	0	30	11	1	5	2	0	0	0	0
	D	2	22	2	3	1	0	2	5	2	12	2	0
	M	0	0	4	0	0	0	3	0	0	0	0	0
Trogidae (scav.)	M	0	0	0	0	0	0	0	0	1	0	0	0
Scarabaeidae (a) (herb.)	P	0	0	0	0	0	0	0	0	0	0	1	0
Scarabaeidae (b) (herb.)	P	0	0	0	0	0	0	0	0	0	0	0	1
Scarabaeidae (c) (herb.)	D	0	0	0	1	0	0	0	0	0	0	0	0
Dynastinae													
Semanopterus leai (herb.)	M	0	0	0	0	0	0	0	0	0	0	0	1
Melolonthinae													
Biphyllocera kirbyana (herb.)	M	0	0	0	0	0	0	0	0	0	0	1	1
Byrrhomorpha ponderosa (herb.)	D	0	0	0	1	0	0	0	1	0	2	0	2
	M	0	0	0	0	0	0	0	0	0	0	0	1
Neophylloctocus (herb.)	P	0	0	0	0	0	0	1	0	11	0	2	0
	D	1	0	0	0	0	0	0	0	0	0	2	2
	M	1	0	0	0	0	0	0	0	0	0	8	2
Elateridae													
Conoderus (herb.)	M	0	0	0	0	0	0	0	0	0	0	0	2
Dermestridae Larva (scav.)	P	4	0	0	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	1	0	0	0	0	0	0	0
Tenebrionidae													
Hylaeinae													
Sympetes (herb.)	P	4	0	0	0	0	3	9	4	35	59	21	42
	D	0	0	0	0	0	0	0	0	0	0	0	1
Hylaeus perforatus (herb.)	M	0	0	0	0	0	0	0	0	0	0	1	1
Ulominae													
Tribolium (herb.)	P	1	0	0	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	0	2	0

Table 1 continued

| | | 1976 | | | | | | | | | 1977 | |
		M	A	M	J	J	A	S	O	N	D	J	F
Tenebrioninae													
Tenebrio molitor Larva													
(herb)	P	0	0	0	0	0	1	0	1	0	0	0	0
Tenebrionidae (e) (herb.)	P	0	0	0	0	0	0	0	0	1	0	0	0
Cerambycidae (herb.)	D	0	0	0	0	0	0	0	0	1	0	0	0
Apionidae													
Apion (herb.)	M	0	0	0	0	0	0	0	0	1	0	0	0
Curculionidae													
Cryptorrhynchinae (herb.)	P	0	0	0	0	1	0	0	0	0	1	0	0
Amycterinae													
Acantholopus lateralis (herb.)	M	0	0	0	0	0	0	0	0	0	1	0	1
Aedriodes innuus (herb.)	M	0	0	0	1	0	0	0	0	0	0	0	0
Amorphorhinus polyacanthus													
(herb.)	D	1	0	0	0	0	0	0	0	0	0	0	0
Dialeptops collaris (herb.)	M	0	0	0	0	0	1	0	0	0	0	0	0
Talaurinus (herb.) ...	D	1	0	0	0	0	0	0	0	0	0	0	0
Amalactinae													
Tranes roei (herb.)	M	2	0	0	0	0	0	0	0	0	0	0	0
Leptopiinae													
Cherrus mastersii (herb.)	M	0	0	0	0	0	0	0	0	0	0	0	1
Essolithna (herb.)	D	0	0	0	0	2	0	0	0	0	0	0	0
Curculionidae (j) (herb.)	D	1	0	0	0	0	0	0	0	0	0	0	0
Curculionidae (k) (herb.)	M	1	0	0	0	0	0	0	0	0	0	0	0
Curculionidae (l) (herb.)	D	0	0	0	3	0	0	0	0	1	1	1	0
Curculionidae Larva (herb.)	D	2	0	0	0	0	0	0	0	0	0	0	0
Scolytinae													
Xyloborus saxeseni (herb.)	D	0	0	0	0	0	0	18	4	0	0	0	0
Coleoptera Larva (un.)	D	0	0	0	0	0	0	0	0	0	1	0	0
Coleoptera Misc. spp. (un.)	P	0	0	0	0	1	2	4	1	0	0	2	0
	D	2	5	17	6	2	6	11	4	8	7	17	1
	M	0	1	0	0	0	1	6	0	1	0	0	0
MECOPTERA													
Bittacidae													
Harpobittacus Larva (scav.)	P	0	0	0	0	4	1	0	0	0	0	0	0
TRICHOPTERA													
Larva (herb.)	D	1	0	0	0	0	0	0	0	0	0	0	0
LEPIDOPTERA													
Pyralidae (?) Larva (herb.)	D	0	0	1	0	1	0	2	0	1	1	0	0
Arctiidae Larva (herb.) ...	D	0	0	0	0	0	0	0	1	0	0	0	0
Noctuidae Larva (herb.)	P	0	0	0	2	0	0	0	0	0	0	0	0
Lepidoptera Larva (d)													
(herb)	P	1	0	0	0	0	0	0	0	0	0	0	0
Lepidoptera Larva (e)													
(herb)	D	0	0	0	0	1	0	0	0	0	0	0	0
Lepidoptera Larva (f)													
(herb)	M	0	0	0	0	0	0	0	0	0	1	0	0
HYMENOPTERA													
Ichneumonidae													
Campopleginae (par.)	D	0	0	0	0	0	1	0	0	1	0	0	0
Ceraphronidae (par.)	D	1	0	0	0	0	0	0	0	1	0	0	0
Scelionidae													
Baeinae (par.) ...	D	3	1	0	0	0	0	1	0	0	0	0	0
Scelioninae (par.)	P	0	0	0	0	0	0	0	0	0	0	0	1
	D	1	1	0	0	1	0	0	0	0	0	0	0
Oxyscelio (par.)	M	1	0	0	0	0	0	0	0	0	1	0	0
Diapriidae													
Diapriinae													
Basalys (par.)	D	0	0	0	0	0	0	0	0	2	0	1	1
	M	1	0	0	0	0	0	0	0	0	0	0	0
Belytinae													
Stylactista (par.)	P	0	0	0	0	0	0	2	0	0	0	0	0
Diapriidae (c) (par.)	D	0	0	0	0	0	0	0	0	0	0	0	1
Mymaridae													
Alaptus (par.)	D	1	0	0	0	0	0	0	0	0	0	0	0
Pteromalidae													
Pteromalinae													
Grahamsia (par.)	D	0	1	0	0	0	0	0	0	0	0	0	0
Encyrtidae													
Genus near *Anisotylus* (par.)	P	0	0	0	0	0	0	0	0	1	0	0	0
Chalcidoidea (par.)	M	0	0	0	0	0	0	0	0	0	0	0	1
Bethylidae													
Parasierola (par.)	D	0	0	0	0	0	0	0	0	0	0	2	0
Pompilidae (a) (pred.) ...	P	0	0	0	0	0	0	0	0	0	0	0	1
Pompilidae (b) (pred.)	M	0	0	0	0	0	0	0	0	0	0	0	1
Tiphiidae													
Tachynomyia ? *aurifrons*													
(par.)	P	1	0	0	0	0	1	0	0	0	2	1	0
Tiphiidae (b) (par.)	D	1	0	0	0	0	0	0	0	0	0	0	0
	M	0	0	0	0	0	0	0	0	0	0	0	1
Formicidae (see Table 5)													

* P—Perth; D—Dwellingup; M—Manjimup.
† (dec.)—decomposer; (herb.)—herbivore; (omniv.)—omnivore; (scav.)—scavenger; (par.)—parasite; (pred.)—predator; (un.)—unknown.

separate category because many species feed on seeds, on saps produced by homopteran bugs or plants, or they are predacious.

In numbers of individuals, the predator/parasite category together with the ant category exceeds the herbivore category at all 3 sites (Tables 4 and 5). The low number of herbivores is regarded as being due to their lower vagilities, and hence probability of being trapped, rather than to their lower densities.

Species richness of herbivores, predators and parasites, collembolans, and ants (Tables 3, 4 and 5) are all greatest at Dwellingup. Manjimup has the lowest number of species in all categories with the exception of herbivores which are least diverse at Perth. The extremely low number of collembolan species trapped at Manjimup (Table 2) is, as mentioned, an artifact. Comparison of the total numbers of individuals of collembolans at each site is not made because of the variations in trapping efficiency (Southwood 1966).

For each category, the number of species trapped each month may be regarded as the index of activity. The numbers of species of herbivores, predators/ parasites, and ants, and also the numbers of individuals of ants trapped each month are compared (using Spearman's rank correlation) with the climatic data for the corresponding month and the previous month; the correlation coefficients and significance values are shown in Table 6. The seasonality observed for each category and the correlations significant at the 0.05, 0.01 and 0.005 probability levels are discussed below.

Herbivores

At Perth, the herbivores show high levels of activity in spring, summer and early autumn. Numbers of species are positively correlated with the temperature of the current and the previous months, and negatively correlated with relative humidity and rainfall (Table 6). The causal agent here is uncertain because temperature is negatively correlated with relative humidity and rainfall.

At Dwellingup, the levels of herbivore activity are less obviously dependent upon the season although a decrease in activity is observed in August-September at a time of high rainfall. The only significant correlation with environmental factors is a negative correlation with the rainfall of the corresponding month (Table 6).

At Manjimup, the herbivores show highest activity levels in early autumn and summer; however, the seasonal trend is less marked than in Perth. The numbers are negatively correlated with the relative humidity and rainfall of the previous month, but the results are not significant at the 0.5 probability level (Table 6).

Table 2

List of Collembola species collected in pitfall traps at Perth (P), Dwellingup (D) and Manjimup (M)

	P	D	M
Dicyrtomidae	+	O	O
Entomobryidae			
Entomobrya lamingtonensis	+	+	O
Lepidocrytoides sp. A	+	+	
Lepidocrytoides sp. B	+	+	+
Lepidosira terraereginae	O	+	O
Lepidosira sp. B	+	O	O
Lepidosira sp. C	O		O
Lepidosira sp. D	O	O	+
Unidentified	+	O	O
Hypogastruridae			
Hypogastrura sp.	O	-	O
Triacanthella sp.	O	+	O
Isotomidae			
Acanthocyrtus plumbeus	O	+	+
Cryptopygus antarcticus	O	+	O
Cryptopygus thermophyla	+	O	O
Isotoma sp. near tridentifera	O	+	O
Isotomurus sp. A	+	O	O
Isotomurus sp. B	+	O	O
Proisotoma sp.	O	+	O
Unidentified, immature	O	+	O
Neauridae			
Brachystomellini sp. A	+	O	O
Brachystomellini sp. B	+	O	O
Brachystomellini sp. C	O	+	+
Brachystomella sp. near paravula	O	+	O
? Subclavontella sp. A	O	+	O
? Subclavontella sp. B	O	+	O
Ceratrimeria sp.	O	+	O
Neanura sp.	O	+	O
Arlesia sp.	—	O	O
Odontellini	O	+	O
Triodontella sp.	O	+	O
Zealandella sp.	O	+	O
Poduromorpha unidentified and immature	+	+	O
Sminthuridae			
Sphaeridia sp.	+	O	O
Sminthurinus sp.	+	+	O
Genus near Katianna	+	O	O
Katianna sp	+	O	U
Genus nov near Sminthurinus	+	—	O
Pseudokatianna sp	O	+	O
Aneuempodulis cinereus	+	O	O
Corynephoria sp A	+	O	O
Corynephoria sp B	O	+	O
Rastriopes dromedarius	+	O	O
Rastriopes sp. B	O	+	O
Temeritas sp.	O	+	O
Unidentified and immature	+	+	O

+ = present   O = absent

Total Collembola species trapped at each site = Perth 22, Dwellingup 29, Manjimup 5.

Table 3

Total numbers of Collembola species collected in pitfall traps each season at Perth and Dwellingup

	Autumn	Winter	Spring	Summer	Total species trapped at site
Perth	21	10	5	6	22
Dwellingup	15	20+	20+	5	29

(2)—17648

Table 4

The numbers of individuals and of species of ants (Formicidae) trapped per month and the total ant species and individuals trapped at each of the three sites

Site	1976 M	A	M	J	J	A	S	O	N	D	1977 J	F	Total species trapped at site	Total individuals trapped at site
						Ant individuals								
Perth	261	55	37	27	21	56	103	65	129	112	208	181		1255
Dwellingup	46	54	65	30	29	36	104	94	84	148	98	84		872
Manjimup	48	54	53	25	27	40	25	86	99	103	102	25		687
						Ant species								
Perth	17	11	12	10	6	8	14	14	17	17	19	16	39	..
Dwellingup	11	12	10	8	7	8	19	17	15	20	18	19	43	..
Manjimup	9	9	8	8	7	8	5	8	9	12	13	10	32	..

Table 5

The numbers of hexapod herbivores, and predators and parasites trapped at each of the three sites: the numbers per month and the total species and the total individuals

Site	1976 M	A	M	J	J	A	S	O	N	D	1977 J	F	Total species trapped at site	Total individuals trapped at site
						Herbivores								
Perth	7	6	2	3	4	4	3	4	5	5	7	5	21	314
Dwellingup	8	2	4	4	6	1	2	6	3	7	4	3	28	98
Manjimup	4	2	2	3	1	2	1	0	2	3	5	1	22	99
						Predators and parasites								
Perth	6	5	6	8	5	6	10	6	8	5	5	4	17	2852
Dwellingup	8	8	6	6	8	4	7	5	11	4	7	4	23	1250
Manjimup	5	3	8	4	3	2	5	5	3	4	3	4	14	364

Table 6

Spearman's rank correlation coefficients and significance values for trapped species (herbivores, predators and parasites, ants), and trapped individuals (ants) against climate of corresponding month and previous month at three sites (n = 12)

Site	Average Temperature§		Relative Humidity		Rainfall	
	Corresponding month	Previous month	Corresponding month	Previous month	Corresponding month	Previous month
			Herbivore species			
Perth	0·75‡	0·67†	−0·75‡	−0·62*	−0·71‡	−0·75‡
Dwellingup	0·27	0·13	−0·10	−0·29	−0·59*	0·08
Manjimup	0·27	0·48	−0·31	−0·41	−0·36	−0·41
			Predator and parasite species			
Perth	−0·60*	−0·44	0·44	0·47	0·41	0·61*
Dwellingup	−0·04	0·12	0·05	0·09	−0·04	−0·17
Manjimup	0·02	0·18	0·17	−0·54*	−0·54*	0·41
			Ant individuals			
Perth	0·76†	0·55*	−0·83‡	−0·66†	−0·84‡	−0·47
Dwellingup	0·52*	0·09	−0·68†	−0·46	−0·32	−0·11
Manjimup	0·45	0·14	−0·45	−0·31	−0·19	−0·12
			Ant species			
Perth	0·78‡	0·53*	−0·86‡	−0·70†	−0·86‡	−0·52*
Dwellingup	0·66†	0·25	−0·78‡	−0·61*	−0·45	−0·30
Manjimup	0·86‡	0·69†	−0·71‡	−0·59*	−0·58*	−0·65

*P < 0·05   † P < 0·01   ‡ P < 0·005   § The average of the monthly maximum and minimum temperatures was used.

Predators and parasites

At Perth, activity of predators and parasites is highest in late autumn and early spring although low in summer. Numbers of species are negatively correlated with the temperature of the corresponding month and positively correlated with the rainfall of the previous month.

At Dwellingup, there is no evidence of any seasonal trend, all the coefficients being extremely low (Table 6).

At Manjimup, as at Perth, most activity is in late autumn and early spring. However, because rainfall is here distributed throughout autumn and spring, as well as in winter, numbers of this feeding group are negatively correlated with the relative humidity of the previous month and the rainfall of the corresponding month (Table 6).

Ants

In terms of the numbers of individuals and species, the Perth and Dwellingup ant faunas show similar patterns with low activity in winter, which increases in spring and summer, and decreases in autumn. Numbers of species and individuals are positively correlated with the temperature and negatively with the relative humidity of the corresponding month at both these sites and negatively correlated with the rainfall of the corresponding month at Perth (Table 6).

Although more ant individuals and species were active in the summer than in the other seasons at Manjimup, there is generally less seasonal variation in the numbers of individuals and species caught than at the other two sites. Both measures were low in September. The species richness of ants at Manjimup is positively correlated with the temperature, and negatively correlated with the relative humidity and with the rainfall of the corresponding and the previous months. Numbers of ant individuals at Manjimup are not significantly correlated with climatic factors (Table 6).

Collembola

Species richness of Collembola is highest in winter at Perth, and high in autumn, winter and spring at Dwellingup (Table 3).

Discussion

As stated in our previous paper (Koch and Majer 1980) the value of undertaking seasonal studies of forest fauna is: (1) to enable a more satisfactory understanding of seasonal influences than solely by using meteorological variables, (2) to reveal the relative importance of various faunal groups in biological processes such as litter decomposition, and (3) to provide a framework of ecological information on which to base forest management decisions.

We are treating the phenology of a single component of the forest and woodland ecosystem, viz. activity/abundance of the invertebrate fauna of the floor layer. Because seasonal events in other strata may differ, the general findings should not be extrapolated to other components of the ecosystem. For instance, in the northern jarrah forest, flowering in the upper strata (e.g. of the relatively deep rooting marri) occurs from February to March (Beard 1970), whereas flowering in most understorey plants occurs in October (Majer 1981).

For each study area, Figure 1 shows the activity of the main groups of forest floor invertebrates described in the present and the previous paper (Koch and Majer 1980). Data on herbivores and ants are from the present paper, predator-parasite data are from both papers, and data on fauna associated with the decomposition process are from a combination of the data in the previous paper and the Collembola data in the present paper. Figure 1 is tentative and generalised since it shows the seasonal relationships rather than the actual values for the index of activity (total species collected each month). We hope these findings will stimulate further phenological work in forests and woodlands.

The three study sites had characteristically different invertebrate phenological patterns. As stated (Koch and Majer 1980), the three sites have different
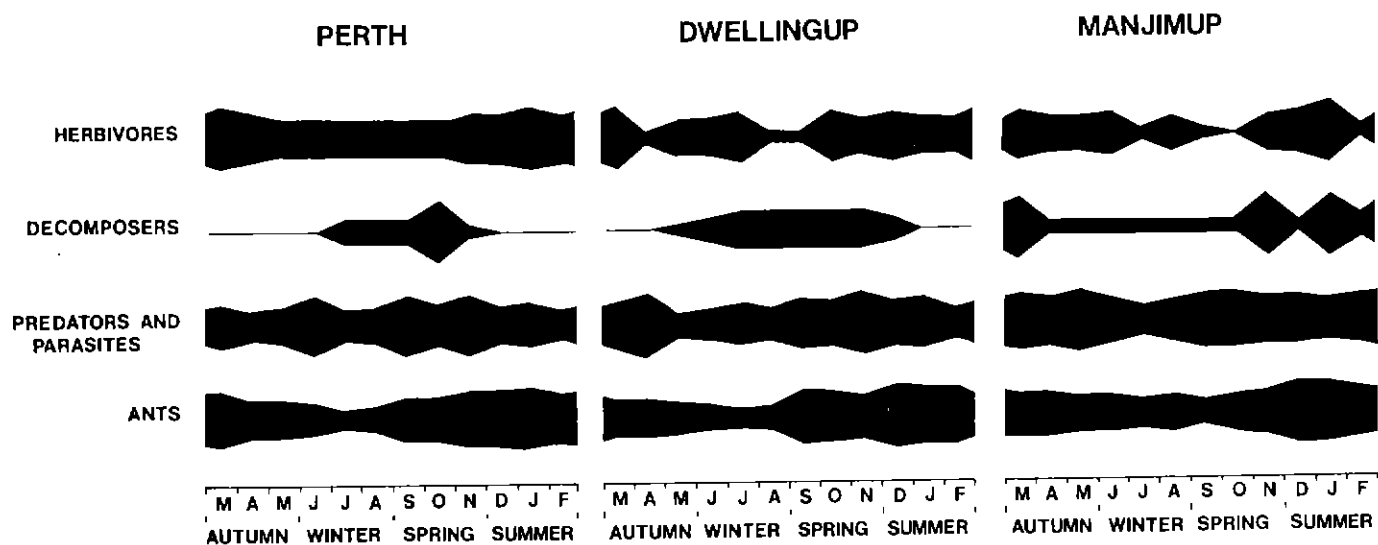

Figure 1.—Schematic diagram of the seasonal activity of herbivores, decomposers, predators and parasites, and ants at Perth, Dwellingup and Manjimup. The width of the bar indicates the level of activity as measured by the numbers of species in each category collected in the pitfall traps.

climatic patterns and soil types; these factors are responsible for concomitant differences in the forest floor micro-environment (Monteith 1973). Basically, the more southern the study site the lower the temperatures and the higher the relative humidities (Koch and Majer 1980). The length of the growing season—a measure of the excess of effective rainfall over evaporation (assuming that temperature is not limiting)—also increases to the south: e.g. it has been calculated as 6.3 months at Perth, 7.6 months at Dwellingup, and 8.0 months at Manjimup (Director of Meteorology 1965, 1966). These estimates are for introduced commercial crops, not native perennials, but the growing periods of these may be expected to increase in the same proportion.

The herbivore activity is negatively correlated with rainfall at these 3 sites, and it increases during spring (Fig. 1). Recently, increases in the activity of grasshoppers during spring in woodlands near Perth have also been recorded (Whelan and Main 1979). Spring is the period when many understorey shrubs exhibit growth flushes (Baird 1977, and D. Backshall, pers. comm. 1980) owing to the increase in available moisture and the warmer temperatures. The decrease in herbivore activity during the cooler months at all 3 sites might be connected with the contemporaneously slower growth rate of certain plant species (Baird 1977), the direct influence of climatic factors on the life cycles of the herbivores or it might be a combination of both factors. Thus the decreases in activity of the herbivores at Dwellingup (during August-September) and at Manjimup (during June-October) (Fig. 1) may be due to the low temperatures during these months.

The length of decomposer activity increases progressively from north to south (Fig. 1). It is largely restricted to the wetter months at Perth and Dwellingup and continues throughout the year at Manjimup. This is probably because humid conditions are apparently present for longer at Manjimup. It would be worthwhile to compare rates and seasonality of litter decomposition at the sites, but no data are available.

Compared to the decomposers, the activity of the predator/parasite category appears less dependent on season. This is probably because a wide range of organisms, with different feeding preferences and whose activities are not in phase, are preyed on or parasitised. The only trends detectable are slight increases in the activity of predators and parasites in the spring and autumn at Perth and Dwellingup (Fig. 1), probably due to the increases in herbivore numbers during those seasons.

It has been demonstrated that the natural feeding rate of ants (Kajak et al. 1972), and hence their activity, was correlated with availability of food. Ant numbers may therefore be a good general indicator of seasonal trends in overall biological activity although the influence of temperature should also be considered. The times of maximum ant activity (Fig. 1), which is in spring and summer at Perth and Dwellingup and summer at Manjimup, may be connected with high temperatures and with food availability. In spring and summer there are abundant food sources such as herbivorous invertebrates (Fig. 1), plant saps (Majer 1981), and seeds. At Perth and Dwellingup decomposers are most abundant during the cooler months. At all 3 sites, however,

the herbivores, and predators and parasites have lowered activity during the cooler months—the resulting reduced availability of such food sources may be one reason for the observed low activity of the ants during the winter.

In the northern hemisphere, seasonal activity of ant communities has also been related to climatic factors, with greatest summer activity occurring around June-August. In Quebec, foraging of the red wood ant, *Formica lugubris* Zett., was largely influenced by temperature, although excessive rain reduced foraging during cool periods (McNeil et al. 1978). In a Polish meadow, ants exhibited greatest activity in June-July, and significantly high numbers of one species were positively correlated with temperature (Woyciechowski and Miszta 1976). In a Chihuahuan desert, increases in temperature, rainfall, and food served as thresholds, but not regulators, of the seasonal foraging activities of ant communities (Whitford 1978).

In the 3 present study areas ant activity, as measured by the numbers of species collected, is positively correlated with the temperature and negatively with the rainfall (Table 6). The high correlation coefficients suggest that the activity has a direct link with these climatic factors rather than an indirect link via the availability of food. The extended period of decreased activity between mid-autumn and late-spring at Manjimup is in keeping with this suggestion because the period of high moisture availability and low temperature persists longer at Manjimup than at the more northern sites, Dwellingup and Perth.

Biological processes in forests and woodlands are related to the periods of activity of living organisms: e.g. pollination and seed dispersal may only occur when particular animals are present; the extent of damage to plants is related to the abundance of herbivores which in turn is affected by the presence of appropriate predators and parasites; and litter decomposition depends upon the action of certain fauna and microflora. This study has suggested that these processes occur at particular periods (phenophases) of the year, which differ at the 3 study sites.

To assist decision-making, managers of forests and woodlands should have information about relevant seasonal events. For instance, the ecological results of the prescribed burn of a forest, of artificial seeding of a disturbed area, or of logging would differ depending upon the times of implementation.

The findings of the present paper indicate that, at least with regard to the ground-living (epigaeic) fauna, marked phenological differences occur between the southern site (Manjimup) and the two northern sites. We recommend that for a better understanding of the ecology of forests and woodlands in the south-west of Western Australia, processes such as litter decomposition, grazing by insects, and seed carrying by animals should be studied simultaneously at northern and southern localities.

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