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Floristic Change on Heron Island, a Coral Cay in the Capricorn–Bunker Group, Great Barrier Reef

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Abstract

Floristic change on islands is a matter of considerable theoretical and practical conservation interest. The vascular flora of Heron Island, a small coral cay on the Great Barrier Reef, Australia was, therefore, surveyed at 3 month intervals from September 1990 until December 1993. During this period 57 species were reported for the island, with the number of species present at one time varying from 40 to 53. Six alien species and two native species were reported from the island for the first time. Direct gradient analysis demonstrated a similarity between spring–summer samples and autumn–winter samples, with the pairs of samples being different from each other. Neither the total number of species present at one time nor the proportion of alien species in the flora has increased since 1984, suggesting that the flora has reached equilibrium with the disturbance caused by human activity on the island. A method for estimating the annual rate of species turnover (I_1) is outlined, and I_1 is calculated for Heron Island and four other islands in the Capricorn–Bunker Group. The low I_1 reported for Heron Island is further evidence for floristic equilibrium being approached on this highly disturbed site.

Introduction

The flora of islands has long been of ecological and biogeographic interest, especially in terms of extinctions and invasions and the consequent idea of an equilibrium flora (MacArthur and Wilson 1967; Simberloff 1978). The flora of coral cays on the Great Barrier Reef has been studied in this light by Buckley (1981) and Chaloupka and Domm (1986). Heron Island, has had floristic surveys undertaken in the years 1927, 1958, 1960 and 1984 , over which time period a steady increase in the proportion of the flora which was composed of alien species was noticed (Chaloupka and Domm 1986). Heatwole (1984) examined records of the terrestrial floras of coral cays in the Capricorn–Bunker group of islands in the southern Great Barrier Reef, which includes Heron Island, and commented on the relatively high rates of introductions and extinctions on these small islands. Heatwole (1984) noted, however, that among the possible sources of error in studies based on published lists of species are nomenclatural confusion and seasonality. Seasonality is dismissed as a significant factor on the assumption that 'most species are present as green plants the year round'; little can be done about nomenclatural confusion.

While Island Biogeography theory may cause it to be assumed that rates of change in species present are likely to be inversely associated with island size, Chaloupka and Domm (1986) have shown that the number of introduced species is closely associated with the number of visitors to the islands. Heron Island, and the other similar cays on the Great Barrier Reef are National Parks, and mostly also subject to disturbance from tourists. The rate of change of the flora on these islands is, therefore, of interest in terms of management for conservation, especially in terms of weed invasion.

During visits to Heron Island in the period 1987–1989, the flora of the island was observed and, following apparent changes, systematic observations commenced in order to

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determine how vagile the flora of Heron Island was, and how this apparent vagility might be influenced by the season in which surveys were made.

Location and Methods

Heron Island

Heron Island is a small coral cay about 800 × 300 m situated 70 km offshore from the Australian continent (Lat. 23°26'S Long. 151°55'E). Much of the island is clad in a dense forest of *Pisonia grandis* trees, with some fringing grasslands (Fosberg 1961). In 1987 the island was extended when rubble excavated from a harbour was dumped on its eastern end, creating a new open habitat which was rapidly colonised (Rogers 1993). Heron Island is one of the Capricorn–Bunker group of islands, and lies within the Capricorn section of the Great Barrier Reef Marine National Park. Heron Island has been occupied by humans since about 1927, with greatly increased numbers of tourists and research workers visiting the island in the last 20 years.

Species Records

At 3 month intervals from September 1989 to December 1993, the flora of Heron Island National Park, including wasteland but excluding gardens, was surveyed by walking a series of transects which traversed all vegetation types on the island and all living vascular plant species listed. Nomenclature of the flora of coral cays is difficult. This is partly because of the dispersal of the islands around the Indo–Pacific region, and partly a reflection of the many small differences within or between the species of island floras (see Fosberg 1988). In this account a broad species concept has been followed. Species were determined to be native or alien according to the criteria of Heatwole (1984).

The number of new species added to the flora of Heron Island and the number of species lost since the survey of Chaloupka and Domm (1986) was determined. The species added to, or lost from, the flora during the study period were examined using each of the first four surveys as baselines.

Estimating Species Turnover

To examine species turnover the statistic I (Lynch and Johnson 1974) was calculated for Heron Island using all available published data as well as those collected during the present study. This statistic has the formula:

$$I = 100(E+H) / (C+D),$$

where E is the number of new species in the flora, H the number of species missing from the flora at the time of second survey but present at the first, C is the number of species present at the first survey and D the number of species present at the second survey. I may be expressed as I per year (I_y) However, both I and I_y are extremely sensitive to the length of the period between studies, a matter noted by Heatwole (1984), and if I_y is plotted against the time interval (T) between successive studies, the line joining the points tends to an asymptote with the abscissa when successive intervals are short, and to an asymptote with the ordinate when time intervals are long. Therefore, if the natural logarithm of I_y ($\ln I_y$) at any time interval is plotted against the natural logarithm of the length of the time interval ($\ln T$), a straight line should result. The intercept of that line on the abscissa represents the annual rate of species turnover since $\ln 1 = 0$, and can be considered a new statistic I_1. This value (I_1) was estimated for Heron Island by pooling data from this study, Chaloupka and Domm (1986) and Heatwole (1984). I_1 could also be calculated directly for Heron Island using four floristic surveys conducted at annual intervals in this study. For comparative purposes I_1 was also estimated using regression studies for Heron, Northwest, Tryon, Masthead and Wilson Islands using previously published data from Heatwole (1984) and Chaloupka and Domm (1986). The relationship between I_1 and island size and number of visitors to the islands (Chaloupka and Domm 1986) was examined using regression analysis. All regressions were calculated using a least-squares model.

Trends in Floristic Composition

A multivariate pattern analysis was used to detect yearly and seasonal trends in the floristic composition of the island. The plant records for the samples (57 species, 14 samples) were analysed by redundancy analysis (ter Braak 1988), with the season and year of sampling as the environmental data set. Redundancy analysis is a constrained ordination technique based on principal components analysis that, in a joint analysis of the two data sets, floristic and environmental, assess the degree to which they show co-variation (ter Braak and Prentice 1989). That is, it seeks patterns among the samples that occur in both data sets, while patterns that are unique to either one of the data sets alone are ignored. This is, thus, a direct gradient analysis technique analogous to canonical correlation analysis, but which avoids many of the mathematical constraints inherent in that technique (ter Braak and Prentice 1989), as these are unrealistic for most biological data sets.

The redundancy analysis produces two inter-related ordination diagrams, one for each of the two data sets, which can be displayed simultaneously in a species–environment biplot. The degree to which the floristic variation associated with the the environmental variables is displayed by the biplot can be assessed by calculating what percentage is shown of the variation shared in common by the two data sets. The degree to which the variability associated with the environmental variables in the direct gradient analysis accounts for the overall variation in species composition among the samples can be assessed by comparing the constrained ordination with the equivalent unconstrained ordination of the species data alone; in this case this involves comparing the results of the redundancy analysis with the results from a species-centred pincipal components analysis.

Results

Over the time studied, a total of 57 species were found growing as native or naturalised species on Heron Island (Table 1); 32 of these species were present at each of the 14 census dates, and 49 were present in each of the years studied. Four species *Coronopus integrifolia*, *Dactyloctenium aegyptium*, *Lycopersicon lycopersicum* and *Salsola kali* were recorded only once or twice, and in each case by only one or two plants. A total of 30 species were judged to be aliens (Table 1).

The total number of species reported from Heron Island in the censuses varied from 40 to 53 and the proportion of aliens in the flora varied between 38 and 50% (Table 2).

Table 1. Species reported from the National Park and wasteland areas on the Great Barrier Reef coral cay Heron Island at 3 month intervals from September 1990 until September 1993

Months of collection are March (M), July (J), September (S), and December (D). + indicates living vegetative plant found, o indicates no living vegetative plant found on the island. Asterisked species are judged to be alien

Species	Year Month	1990 SD	1991 MJSD	1992 MJSD	1993 MJSD
Abutilon albescens Miq.		++	++++	++++	++++
Achyranthes aspera L.		++	++++	+++o	++++
**Amaranthus viridis* L.		++	++++	++++	++++
**Apium leptophyllum* (Pers.) F.Muell.		++	o+++	o+++	++++
**Argemone ochroleuca* Sweet		oo	o+++	o+++	oooo
**Bidens pilosa* L.		+o	++++	++++	++++
Boerhavia tetrandra Forster f.		++	++++	++++	+++
**Brachiaria subquadripara* (Trin.) A.Hitchc.		+o	++++	++++	++++
**Bromus catharticus* M.Vahl.		+o	o+++	oo+o	oo++
**Cakile edentula* (Bigel.) Hook.		++	++++	++++	++++
**Calyptocarpus vialis* Less.		++	++++	++++	++++
**Capsella bursa-pastoris* (L.) Medik.		++	++++	+++o	o++o
Cassytha filiformis L.		oo	o+++	+++o	+ooo
Casuarina equisetifolia L. var. *incana* Benth.		++	++++	++++	++++
Celtis paniculata (Endl.) Planchon		++	++++	++++	++++
**Cenchrus echinatus* L.		+o	++++	++++	++++
Commicarpus insularum Meikle		++	++++	++++	++++
**Conyza bonariensis* (L.) Cronq.		++	++++	++++	++++
Cordia subcordata Lam. & Poiret		++	++++	++++	++++
**Coronopus didymus* (L.) Smith		+o	++++	o++o	++++

Table 1 continued

Species	Year Month	1990 SD	1991 MJSD	1992 MJSD	1993 MJSD
**Coronopus integrifolius* (DC.) Sprengel		oo	oooo	o++o	oooo
**Cynodon dactylon* (L.) Pers.		++	++++	++++	++++
**Dactyloctenium aegypticum* Willd.		oo	o+oo	o+oo	oooo
**Delonix regia* (Bojer) Raf.		++	++++	++++	++++
**Digitaria ciliaris* (Retz.) Koel.		+o	++o+	++++	++++
**Eleusine indica* (L.) Gaertner		++	++++	++++	++++
Euphorbia atoto Forster f.		++	+ooo	oooo	o+++
**Euphorbia cyathophora* Murray		++	++++	++++	++++
**Euphorbia hirta* L.		oo	oooo	ooo+	+++o
**Euphorbia prostrata* Aiton		oo	++oo	++oo	++++
Euphorbia tannensis Sprengel		++	++++	++++	++++
Ficus opposita Miq.		++	++++	++++	++++
Gnaphalium luteo-album L.		++	++++	o+++	++++
Ipomoea macrantha R. & S.		oo	oooo	++++	++++
Ipomoea pes-caprae L. ssp. *brasiliensis* (L.) v.Osstr.		++	++++	++++	++++
**Lepidium virginicum* L.		++	++++	++++	++++
Lepturus repens (G.Forster) R.Brown		++	++++	++++	++++
**Lycopersicon lycopersicum* (L.) Karst .		oo	oo+o	oooo	ooo+
Malvastrum coromandelianum (L.) Garcke		++	++++	++++	++++
Pandanus tectorius Parkinson ex Z.		++	++++	++++	++++
Pipturus argenteus (G.Forster) Wedd.		++	++++	++++	++++
Pisonia grandis R.Br.		++	++++	++++	++++
**Poa annua* L.		+o	++++	o++o	++++
**Portulaca oleracea* L.		++	++++	++++	++++
Salsola kali L.		oo	+ooo	oooo	oooo
Scaevola taccada (Gaertn.) Roxb.		++	++++	++++	++++
Sesuvium portulacastrum (L.) L.		o+	++++	++++	oooo
**Sisymbrium orientale* L.		++	o+++	++++	++++
**Solanum americanum* Miller		++	o+++	++++	++++
**Sonchus oleraceus* L.		+o	++++	++++	++++
Sporobolus virginicus (L.) Kunth		++	++++	++++	++++
**Stenotaphrum micranthum* (Desv.) G.E.Hubbard		++	++++	++++	++++
Suriana maritima L.		++	++++	++++	++++
Thuarea involuta (Forster) R.Br.		++	++++	++++	++++
Tournefortia argentea L.f.		++	++++	++++	++++
Tribulus cistoides L.		++	++++	++++	++++
Wedelia biflora (L.) DC.		++	++++	++++	++++

Table 2. Numbers of native and alien species together with the total number of species and percentage of all species which are alien reported for Heron Island, Great Barrier Reef, in the period September 1990 to December 1993

Date	Year Month	1990 SD	1991 MJSD	1992 MJSD	1993 MJSD
Native		24 25	26 25 28 25	25 26 26 24	25 25 25 25
Alien		23 15	20 25 25 24	20 26 25 21	23 24 25 24
Total		47 40	46 50 53 49	45 52 51 45	48 49 50 49
Percentage alien		49 38	43 50 47 49	44 50 49 47	48 49 50 49

When floristic lists for 1984 (Chaloupka and Domm 1986) and 1993 are compared it is seen that five species have been lost from the Heron Island flora, all of them alien species, and ten species have been added to the flora of which three are native (Table 3). Seven of the species added to the flora since the 1984 survey have not been reported in earlier studies.

Table 3. Changes in the flora of Heron Island, Great Barrier Reef, between the survey of Chaloupka and Domm (1986) and the year 1993

Asterisked species have not been reported in the literature as naturalised for Heron Island

	Species lost	Species gained
Aliens		
	Eragrostis tenuifolia	*Euphorbia hirta*
	Kalanchoe tubiflora	**Dactyloctenium aegyptium*
	Oxalis corniculata	**Brachiaria subquadripara*
	Panicum maximum	**Calyptocarpus vialis*
	Tetragonia tetragonoides	*Capsella bursa-pastoris*
		Coronopus didymus
		**Lycopersicon lycopersicum*
Natives		
		Ipomoea pes-caprae
		**Ipomoea macrantha*
		**Sesuvium portulacastrum*

Neither the total number of species detected nor the presence of particular species appears to be strongly related to season (Tables 1 and 2). The use of successive starting dates to examine the numbers of species lost from the flora or added to the flora, however, shows great variation in the apparent changes in species composition of the flora (Table 4). For example, if the survey had begun in September 1990 and been repeated in September 1993, three new species would have been noticed, none would appear to have been lost, whereas in that time, a cumulative total of eleven species not present in the original survey would have appeared on the island. On the other hand, an initial survey in December 1990 with a repeat survey in December 1993 would have shown nine new species to be present, with two original species lost; whereas in that time a total of 19 species not present on the island in December 1990 had appeared on the island.

When regressions relating $\ln I_y$ to $\ln T$ were calculated, a highly significant linear relationship ($P < 0.001$) with high r^2 values was discovered in each case (Table 5). The annual rate of species turnover I_1 for Heron Island was estimated as 9.43 ± 1.18 species by regression studies using all available data. The mean of four independent 1 year species change studies was 9.47 ± 1.65 species: I_1 calculated for Heron Island using only previously published data was 9.92 ± 1.24 species. I_1 estimates for the other Islands together with estimates of area and numbers of visitors are provided in Table 5.

The first two axes of the species–environment biplot from the redundancy analysis of the floristic data are shown in Fig. 1. The similarities among the samples are indicated by the spatial realtionship of the points—points near each other show more similarity among themselves, based on floristic characteristics, than do points further away. These two axes account for 55.2% of the variation shared in common between the floristic and environmental data sets (all six axes are needed to display 100% of the variation). In turn, these two axes also account for 80.8% of the variation shown by the first two axes of the equivalent principal components analysis of the species data alone, and thus the yearly and seasonal variations account for most of the variability in species composition between the sampling times.

Table 4. Species occurrence using four sequential initial starting dates for survey of the flora of Heron Island, Great Barrier Reef

'Initial' indicates the number of species recorded for Heron Island at the given date (in bold) and the successive figures indicate the number of those initial species still present on the Island in subsequent surveys. 'New' indicates the number of species not present in the initial species number which are present at the date indicated, and 'lost' indicates the number of initial species no longer present in the flora. 'Cumulated new' indicates the cumulative number of new species recorded since the initial date of survey

Initial period / Year	1990		1991				1992				1993			
Month	S	D	M	J	S	D	M	J	S	D	M	J	S	D
September 1990														
Initial	**49**	40	48	48	47	47	40	47	48	44	43	47	49	47
New		1	2	6	5	4	4	7	4	6	4	4	3	3
Lost		9	1	1	2	2	9	2	1	5	6	2	0	2
Cumulated new		1	3	5	6	6	7	9	9	11	11	11	11	11
December 1990														
Initial		**42**	41	40	41	40	35	41	41	40	37	40	41	40
New			8	13	10	11	8	11	12	10	8	7	10	9
Lost			1	2	1	2	7	1	1	2	5	2	1	2
Cumulated new			8	13	13	13	15	17	17	19	19	19	19	19
March 1991														
Initial			**49**	48	46	47	41	47	47	45	44	47	48	46
New				6	6	5	3	7	6	5	4	4	3	4
Lost				1	3	2	8	2	2	4	5	2	1	3
Cumulated new				6	6	6	8	9	9	11	11	11	11	11
June 1991														
Initial				**54**	51	52	42	51	51	47	45	47	49	47
New					0	0	2	3	2	3	2	3	3	7
Lost					3	2	12	3	3	7	9	7	5	2
Cumulated new					0	0	2	3	3	5	5	6	6	6

Table 5. Annual rates of species turnover (I_1) for Heron Island and selected other islands in the Capricorn–Bunker Group (Great Barrier Reef), with estimates of island area and annual numbers of visitors (Chaloupka and Domm 1986)

I_1 is estimated for Heron Island: (a) using all available data; (b) using only previously published data; and (c) as the calculated mean of four 1 year species turnover measures. r^2 values are those for the equations from which I_1 values were calculated

Island		I_1	r^2	Area (ha)	Visitors
Heron	(a)	9.43 ± 1.18	0.905	19	11,000
	(b)	9.92 ± 1.24	0.828		
	(c)	9.47 ± 1.67			
North-west		12.46 + 1.23	0.893	105	1,100
Wilson		20.24 ± 1.42	0.950	6	14
Tryon		22.88 ± 1.24	0.981	11	336
Masthead		47.68 ± 1.42	0.977	40	314

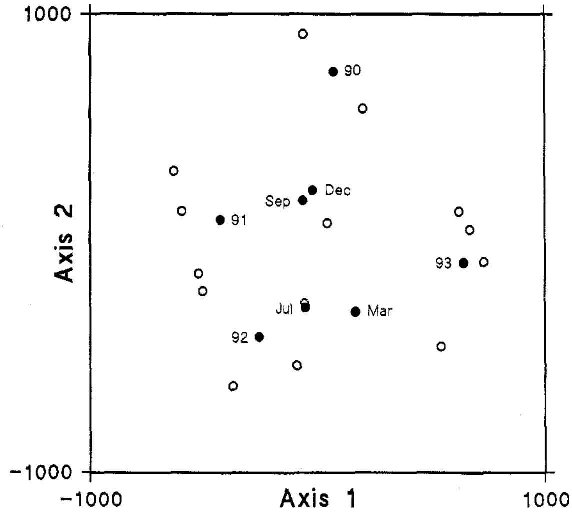

Fig. 1. Projection of the samples onto axes representing the first two components of the species–environment biplot from the redundancy analysis of the floristic composition data. The floristic similarities of samples are indicated by the spatial relationship of the symbols; the open circles are the 14 samples, and the closed circles are the centroids of the four sampling years (90, 1990; 91, 1991; 92, 1992; 93, 1993) and the four sampling seasons (Mar, March; Jul, July; Sep, September; Dec, December).

The analysis indicates that spring and summer samples, averaged across all years, were consistently similar to each other, as were the autumn and winter samples, and that these seasonal pairs were quite different from each other. This similarity is due primarily to the consistent presence of *Bromus catharticus* only in spring and summer, and the consistent presence of *Euphorbia prostrata* only in autumn and winter.

Furthermore, the 1991 and 1992 sampling years, averaged across all seasons, were similar to each other, and quite different from either the 1990 or 1993 sampling years. This similarity is primarily due to the consistent presence of *Argemone ochroleuca* and *Cassytha filiformis* in 1991 and 1992.

Discussion

Based on the figures in the present study and those reported in Heatwole (1984) and Chaloupka and Domm (1986) the flora of Heron Island appears to have stabilised at about 50 species with about half of these being alien. The proportion of the flora composed of aliens over the period of the present study never exceeds that reported by Chaloupka and Domm (1986), suggesting that a new equilibrium floral composition has been arrived at following the increased human impact on Heron Island over the past fifty years.

While seasonality as distinct from vagaries of the weather appears not to influence greatly the number of species found on Heron Island during the period of this study, the number did vary considerably, as did the composition of the flora. Attempts to determine changes in the flora of this or any other small island based on a single survey would, therefore, be of limited value, for they may relate more to variation in recent weather patterns than to any longer term change. The clear difference between spring–summer and autumn–winter samples demonstrated by direct gradient analysis emphasise the importance of season in this respect. The impact of the accretion to an island of a new exposed region such as the rubble patch on Heron (Rogers 1993) is also likely to be significant, and overshadow any long-term changes.

Surveys of living vegetative phases of the plants making up a flora exclude a very important component of the total flora; a vegetation is also comprised partly of a bank of viable seeds stored most commonly in the soil (Leck *et al.* 1989). The presence of these usually invisible components of the flora makes determination in any final sense of the plants present in a flora difficult. Short-lived annuals, for example, exist only as seed for a significant part of their life, and it is well known that they may live as seeds for many years. The absence of the vegetative phase of a plant from a flora is not, therefore, equivalent to extinction. It is also true, that if a plant appears in a flora after an absence of several years it is far from certain that it has arrived as an invader: it may merely have germinated on the first occasion on which conditions suited to growth have occurred.

Of the alien species added to the flora, *Euphorbia hirta*, *Dactyloctenium aegyptium* and *Lycopersicon lycopersicum* must be considered incidental occurrences which, given their fleeting records in this survey, could well have been present and disappeared before. *Calyptocarpus vialis* and *Capsella bursa-pastoris* are now very widespread in waste areas around areas of human activity. *Brachiaria subquadripara* was first seen as a single plant in a waste area in September 1990, disappeared, and then spread rapidly throughout short grass areas in the vicinity of buildings, becoming rare again by December 1993. The alien species *Argemone ochroleuca* which grew only on the exposed rubble from the harbour (but had previously been recorded from Heron Island (Chaloupka and Domm 1986) is evidently a reintroduction of a species to the island, for it had not been seen in recent years on the island, and could not have survived as seeds in the harbour sediments.

The new native species are of special interest. *Ipomoea pes-caprae* has been reported previously from the Island, but was absent for many years. Both *Ipomoea pes-caprae* and *Sesuvium portulacastrum* appeared on a new habitat created on Heron Island following dredging of the harbour, the colonisation of which has been discussed by Rogers (1993). *Ipomoea macrantha*, however, appeared as a single persistent plant on the northern section of the island where turtle nesting could easily destroy the plant. It appears that these three species are unable to compete effectively with the dense grass cover which dominates much of the island, and can therefore only germinate and persist if open areas are available.

Failure to reject the null hypothesis that I_1 is indpendent of area and number of visitors, is, perhaps, not surprising, for a study with so few samples has very limited power. Only the most striking relationship could be substantiated using such a small sample (Brown *et al.* 1993).

It is surprising that Heron Island, the most visited and most disturbed of the islands, has the lowest annual rate of species change of the islands studied. The values for I_1, however, are not statistically significantly related to either size of the island, the number of visitors, or related to a combination of the two attributes when a multiple regression approach is applied. The low value for Heron Island may have been considered an artifact of the large number of floristic surveys undertaken by a single worker, especially over 1 and 2-year periods. However, this is seen not to be so, for when the data from this study are excluded and I_1 for Heron Island calculated using only previously published data the value is similar to the values estimated using all data, and using the mean of all 1 year replacement values. It seems likely that the very high number of visitors over a very long time period maintain a constant (and high) level of disturbance on Heron, whereas the other islands have a more intermittent disturbance regime, and hence gain and lose species more often.

The statistic I_1 appears to provide a reliable estimate of species turnover rates on Heron Island, and allows similar islands to be compared in terms of turnover rates despite the heterogenous nature of the data available. I_1 makes available the short term estimate of I which Heatwole (1984) considered desirable.

The heavy human use of Heron Island in recent years as a tourist resort and research station does not appear to have had a substantial impact on the floristic composition of the island beyond established gardens. The small increase in reported alien species and the low I_1 indicate that a new equilibrium state has developed in the island's flora following initial settlement nearly 70 years ago.

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