Site Fidelity and Return Migration of Tagged Red Hinds (*Epinephelus guttatus*) to a Spawning Aggregation Site in Bermuda

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ABSTRACT

A tag-recapture study of red hinds (*Epinephelus guttatus*) at a spawning aggregation site at the east end of the Bermuda platform commenced in June 1993. Specimens were captured at the site with handlines during the peak summer spawning period and were subsequently winded, tagged and released at the capture site. One year later (mean time at liberty = 360 days) a total of 12 tagged specimens were recaptured at the site (15.2% recovery rate) demonstrating site fidelity over an annual cycle. In the summer of 1994, a total of 110 specimens were captured at this same aggregation site and were subsequently tagged and released. Fifteen of 34 specimens (44%) released at the site were recaptured there with a mean time at liberty of 14 days. These data provide an estimate of residence time at the aggregation site during the spawning period. The remaining 76 specimens were released at various sites distant from the aggregation site. Fourteen of these specimens demonstrated return migration to the aggregation site from different directions covering distances ranging from 2.3 km in three days to 20.1 km in seven days. Three of the tagged specimens demonstrated return migration from different release sites in succession. The longest duration at liberty for a displaced specimen which returned to the aggregation site was 333 days. It is suggested that learned behaviour may play a role in the return migration movements. These results demonstrate that red hinds: 1) show a high degree of spawning aggregation site fidelity over time 2) appear to have a well-developed navigational ability as evidenced by return migration events covering up to 20.3 km from different release sites.

KEY WORDS: Red hind, spawning aggregation, tagging, movements, Bermuda

INTRODUCTION

The groupers (Serranidae) are amongst the most important food fish families found on coral reefs. They often comprise a significant proportion of the commercial fishery landings in tropical countries (Polovina and Ralston, 1987). In Bermuda, groupers dominated the commercial fishery catch through the early 1970s. In 1975, the first reliable, quantitative estimates of fishery landings were available through a recently established commercial fishery landings reporting system. In that year, a total of 204,896 kg (452,000 lbs) of groupers were reported landed and the red hind *Epinephelus guttatus* was the single most important species comprising over one-third (68,903 kg or 152,000 lbs) of total grouper landings (Luckhurst, 1996). During the next six years, landings of all commercially important groupers declined dramatically with red hind landings down by 68% while other species such as the Nassau grouper (*E. striatus*) declined by 95% and became commercially extinct (Luckhurst, 1996). The decline in Nassau grouper landings was attributed largely to excessive fishing pressure with fish pots at its known spawning aggregation sites. In contrast, the two main spawning aggregation sites of the red hind, at opposite ends of the island, have been seasonally closed to fishing during the spawning period since 1974 and although enforcement of these closures has not prevented some poaching, this measure is thought to have helped to maintain spawning stock biomass (Luckhurst, 1996). A recent study of the seasonal closure of a red hind spawning aggregation site in the U.S. Virgin Islands demonstrated significant positive effects on the population from the area closure (Beets and Friedlander, In press).

Domeier and Colin (1997) reviewed the literature on tropical reef fish spawning aggregations and proposed definitions for two aggregation types, resident and transient. They also proposed the use of four criteria to evaluate the nature of a given spawning aggregation. The application of these criteria to the data available on red hinds in Bermuda indicate that they form transient spawning aggregations at specific sites for limited time periods each year. The same site has been shown to be used over several years (this study) which is similar to the findings for red hinds in Puerto Rico (Shapiro *et al.*, 1993). The evaluation of site fidelity and movement patterns in relation to spawning aggregation sites has important implications for fisheries management. If site fidelity is strong then sustained high levels of fishing mortality at a given site during the spawning period has the potential to significantly reduce spawning stock biomass. If biomass/fish density drops below some critical threshold level then the spawning aggregation may cease to form or reproductive output may be drastically reduced possibly affecting future fishery yields (Sadovy, 1994). Movements of the grouper *Plectropomus leopardus* on the Great Barrier Reef, Australia were monitored in relation to spawning aggregation sites using ultrasonic telemetry and strong site fidelity was demonstrated (Zeller, 1998). In addition, catchment distances and residence times at aggregation sites were also estimated.

Studies of red hind biology in Bermuda have been limited. Burnett-Herkes (1975) examined the fishery biology of red hinds including reproduction, age and growth and food habits. He determined that red hinds aggregated at several different locations to spawn and that the same areas were used in the two years of his study. He tagged and released a total of 400 red hinds at a spawning aggregation site during his study but only had seven tag returns. These recaptures indicated differential movement away from the site with a mean distance of 5 km. On a smaller scale, Bardach (1958) demonstrated that red hinds show a strong tendency to return to a home reef if displaced. Nine of the 12 tagged fish which he displaced to an adjacent reef 70 m away were recaptured on their home reef. No other tagging work on red hinds has been conducted in Bermuda until the present study.

MATERIALS AND METHODS

Sampling, tagging and recapture of red hinds from the Eastern Protected Area (EPA) spawning aggregation site commenced on June 28, 1993 and ended July 5th (two days after the full moon). In 1994, sampling commenced earlier (May 31st) with intermittent sampling continuing until the apparent termination of spawning activity (August 4th). Additional fishing expeditions to the site were conducted in November 1994, December 1994 and March 1995. Sampling at the aggregation site in 1995 commenced on May 15th and continued through until July 13th when the aggregation had apparently disappeared. The results presented here were obtained during the above sampling periods.

Sampling

Fishing expeditions were conducted by Division of Fisheries staff on board the fisheries research vessel *R/V Calamus*. Red hinds were caught by hook (size nos. 4 - 8) and line using a variety of baits, mainly squid and halfbeaks (Hemiramphidae). Fish were raised to the surface as slowly as practicable but the majority reached the surface with expanded swim bladders. Landed specimens were immediately placed on a work table and the eyes and dorsal surface of the body were covered with a wet cloth. The specimen was then winded with an 18 gauge hypodermic needle by a single puncture of the swim-bladder through the flank, mid-way along the centre-line of the retracted pectoral fin. Fish were immediately placed in live-wells or tanks which were maintained with constant water exchange using a small electric circulating pump. When fishing terminated, specimens were removed from the live-wells with a dip net and were measured, tagged and released.

Measurements and Tagging

Fork lengths (FL) were determined to the nearest 5 mm during the first year of the study (1993). Thereafter, FL was measured to the nearest 1mm. Specimens were tagged with Floy T-bar anchor tags inserted between the pterygiophores in the left flank below the first soft dorsal fin rays. The visible portion of the tags were yellow plastic, 18 mm in length, labelled "Fish. Div." with a six-digit number code in black. During the 1994 winter fishing expeditions, I started to double-tag specimens (with an additional tag on the right flank) due to observed tag loss (yellow plastic number portion) since the study commenced. All specimens from this time period onward were doubletagged. Tagged fish were released immediately after tag application above an area of reef substrate and all fish were observed to swim rapidly downward toward the substrate upon release. Fork length, tag number(s), location caught and site released were recorded for each fish. Each position was determined using a GPS unit on board the research vessel. The same information was recorded for tag recoveries, however obliterated or unreadable tags were replaced and the substitute number noted.

RESULTS AND DISCUSSION

Domeier and Colin (1997) provided a general definition of a spawning aggregation - " a group of conspecific fish gathered for the purpose of spawning, with fish densities or numbers significantly higher that those found in the area of aggregation during the non-reproductive periods". They suggested that both elements of this definition should be satisfied in order to apply the term spawning aggregation to a group of conspecific fish at a given site. First, it must be demonstrated that fish at the site are spawning or capable of spawning. This is best accomplished by making spawning observations in the field but as this is often difficult, indirect methods such as the occurrence of running-ripe specimens collected from the site may be the only feasible method. In both 1993 and 1994, a number of specimens collected at the site were observed to be in running-ripe condition. Females which died after capture frequently had hydrated eggs in the ovaries. Second, using catch per unit effort data (number of fish caught per hook hour) as a crude index of abundance, I have been able to document significant increases in density of fish at the site during the spawning season compared with values obtained in the non-reproductive season (Luckhurst and Hateley, In prep). This methodology was used in the present study because it was not possible to have divers survey the site to estimate red hind abundance due to logistical constraints. However, Shapiro *et al.* (1993) were able to demonstrate increased abundance over a one week period at their study site in Puerto Rico using diver census estimates of abundance. Thus, the above results meet the two established criteria and validate my site as a red hind spawning aggregation.

Description and Seasonality of Spawning Aggregation Site

The study site was located approximately 11 km NE of St. David's Head near the eastern boundary of the Bermuda reef platform (Figure 1) within a seasonally closed fishing area. The site is on the seaward slope of a ridge in 22 - 32 m depth. The shelf edge of the reef platform, where the slope increases rapidly and drops off into deep water, is only 300 - 400 m seaward of the aggregation site.

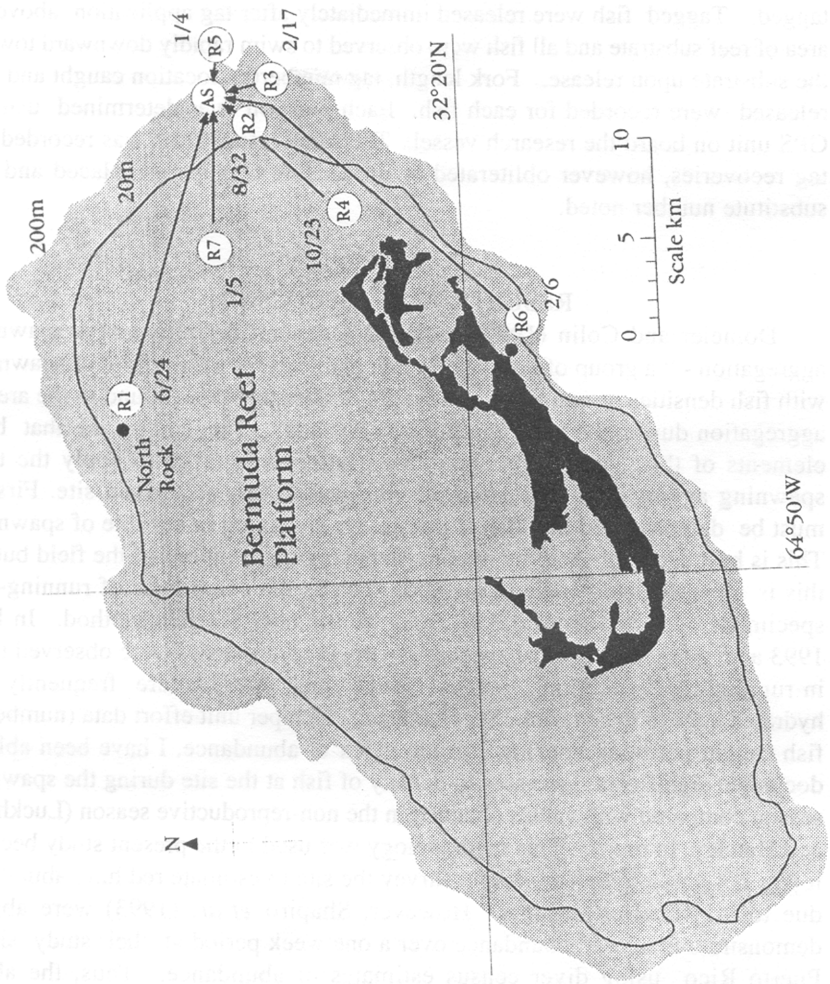

Figure 1. Release sites (R1 - R7) of tagged red hinds in 1994 - 95 from which return migration events were documented. Straight lines from release sites to the aggregation site (AS) indicate minimum distances and do not represent proposed routes. The numerical fractions at each release site indicate the number of specimens which were recaptured at AS (numerator) in relation to the total number released at that site (denominator).

My data indicates that formation of the spawning aggregation usually commences in May with a probable maximum duration of three lunar cycles. The aggregation does not appear to fully form until the water temperature reaches approximately 25 °C. Peak spawning usually occurs in June in the week before the full moon. However, there appear to be inter-annual variations in this general spawning pattern probably caused by oceanographic events which affect the timing and rate of water temperature change. In addition, the timing of the lunar cycle, specifically the date of the full moon, in conjunction with water temperature may influence the initial formation and number of individuals at the aggregation site in May. June appears to be the primary spawning month with the greatest number of individuals at the site. Shapiro *et al.* (1993) found considerable inter-annual variation in the abundance of red hinds over a seven year period at their aggregation study site in Puerto Rico.

It is not known whether females spawn in two consecutive months but Sadovy *et al.* (1994) found that, although they are determinate spawners, that individual females may spawn more than once over the course of the aggregation. There is evidence that this occurs in Bermuda. A large female (55 cm FL) captured at the aggregation site in May 1994 and strip-spawned in captivity for a mariculture program was tagged and released at the site after several days in captivity. This same specimen was recaptured at the site approximately four weeks later and was found to be in spawning condition again with hydrated eggs present.

Site Fidelity

In the first year of this study (1993), sampling was confined to a seven day period (June 28 - July 5) around the full moon during the expected peak spawning period. Sampling was conducted only at a spawning aggregation site in the Eastern Protected Area (Figure 1). A total of 104 red hinds were caught during this period; 79 of these specimens were tagged and released at the site on the day of capture. The remaining specimens were kept as broodstock for an experimental mariculture program.

In 1994, the sampling period was extended (May 31 - August 4) and a total of 152 red hinds were caught at the same EPA site. A total of nine tag recaptures from 1993 were recorded while the numbers on the tags of three other specimens were unreadable. These three specimens were also scored as recaptures due to the algal growth on the tag stubs and the fact that no other tagging had been done on red hinds for 20 years. This total of 12 recaptures represents a tag recovery rate of 15.2%. It is not possible to ascertain from these recaptures whether these specimens moved away from the site after tagging/ release and then returned during the next spawning period or simply remained in the vicinity of the site over the approximately one year period. In any event, these results provided the first evidence of site fidelity in the present study over an extended period. It is probable that this site fidelity is associated with the annual spawning period rather than being a part of the home range of these 12 specimens. No specimens were sacrificed to determine sex and spawning condition due to the uncertainty surrounding the status of the aggregation site but incidental mortality during the program provided the opportunity to evaluate spawning condition. The sizes and times at liberty of the red hinds recaptured in 1994 are given in Table 1. The size range at tagging was 35 - 53.5 cm FL while the mean time at liberty of these 12 recaptured specimens was 360 ± 6.9 (1 SD) days. The growth increments associated with these recaptured specimens were used to estimate growth parameters (Luckhurst and Hateley, In prep). These results provide evidence that these tagged specimens returned to the spawning aggregation site where they were first captured and were present almost exactly one year later. It is not known how long the specimens were present at the site before they were recaptured but sampling was conducted regularly at the site before this apparent peak spawning period and no tagged specimens were captured. Thus, it appears as if these specimens were entrained in their spawning cycle to return after 12 lunar cycles provided that the other environmental parameters (e.g. water temperature) were in the appropriate range.

Table 1. Tagging data from red hinds released at the EPA spawning aggregation site from June 30 - July 5, 1993. A total of 12 specimens were recaptured at the site in 1994. XXX represents an unreadable tag. See text for details.

Tag #	Size at tagging (FL cm)	Days at Liberty
003	50.5	351
027	48.0	356
029	53.5	369
030	52.5	359
032	51.5	356
037	38.5	369
039	50.5	369
048	55.0	357
078	46.0	356
XXX	35.0	352-357 *
XXX	49.5	368-373 *
XXX	43.0	360-365 *

* estimated time at liberty based on date of recapture

During the 1994 sampling period, a total of 110 specimens were tagged and released. However, only 34 of the specimens were released at the capture site while the remainder (76) were displaced from the site at various distances and in different directions (see Return migration section). Unlike the first year of sampling which was very limited, sampling in 1994 continued through into August and some of the specimens released earlier in the summer at the EPA site were recaptured after relatively short periods. Fifteen of the 34 specimens (44.2%) which were released at the EPA site during the summer were recaptured (Table 2). These data provide estimates of potential residence times at the aggregation site. However, these recaptures provide no insight into whether specimens have moved away and returned to the site or remained at the aggregation site during the time at liberty. A tracking method such as acoustical tagging would be required to elucidate **detailed** movement patterns.

Table 2. Short term recaptures (N = 15) of red hinds tagged and released at the EPA spawning aggregation site during the 1994 summer sampling program. All but two of the specimens were re-released. Days at liberty can be used as an index of residence time at the aggregation site.

Tag #	Size at Tagging (cm FL)	Days at Liberty
094	33.5	46
096	27.5	20
098	40.0	17
099	51.5	7
100	48.5	17
102*	54.5	20
110	34.5	7
111	40.0	1
		2
112	48.5	13
116*	37.5	8
127	51.5	6
128	54.0	9
131	44.5	6
176	33.0	12
186	30.0	13

* died after recapture

There was a total of 53 tagged fish recaptured during the study period (some represented multiple recaptures) and 13 of these specimens (24.5%) had the yellow number portion of the tag missing. This level of tag loss prompted the commencement of double-tagging. The tag losses may have resulted from the red hind's typical behaviour of lurking under ledges or in holes on the reef and the tags may have been abraded against the substrate. These tags may not have been sufficiently robust for specimens of this size and weight.

A working hypothesis of the dynamics of a spawning aggregation is that red hinds move to a given aggregation site from surrounding areas (of unknown catchment area), possibly using learned behaviour, and when the density of fishes reaches some threshold level, courtship and spawning behaviour are elicited. It is not known whether fishes leave the aggregation site shortly after spawning or remain in the area to possibly spawn on the same lunar phase one month later. It is also not known whether there is differential movement by sex with females leaving after spawning and males remaining on the site to possibly spawn with other females when they arrive. Shapiro *et al*. (1993) determined that red hinds formed clusters within the aggregation usually consisting of one male and several females. Their observations suggested that spawning was not random but occurred in these clusters. Zeller (1998) determined that males spent an average of eight times longer at aggregations than females and were more likely to make several trips to spawning aggregations than females. This longer residence time at the aggregation site implies that males may be more vulnerable to fishing pressure at the site. Given the female-biased sex ratio of red hinds at spawning aggregation sites (Shapiro *et al*., 1993), this may have detrimental effects on the reproductive output of the aggregation. Macroscopic evaluation of specimens in the field indicates that males appear to be in running-ripe condition for longer periods than females which seem to peak to spawning readiness for only a few days. Sadovy *et al*. (1994) determined that, although females had mature, ripe ovaries for several months, spawning activity was limited to about two weeks each year.

Return Migration

For the purposes of this study, I define "return migration" as the return of tagged specimens to their original capture site (spawning aggregation site) after geographical displacement from the site in various compass directions.

The results from the tagging and displacement of red hinds demonstrated that they have a well-developed ability to navigate in coral reef habitats. As most of the displacements took place during the spawning period, it seems probable that the apparent drive to return to a given aggregation site for spawning was the motivating force for their navigational performance. The return migration events documented during this study (Table 3) suggest that the migration mechanism is highly developed as specimens returned to the same aggregation site on the reef (estimated to be within 20 m based on GPS coordinates) from different compass directions and different distances. It is not known how red hinds navigate in their coral reef habitat when they return to an aggregation site but it is possible that learned behaviour may be involved as suggested for a congeneric species, the Nassau grouper *E. striatus* (Domeier and Colin, 1997). Stevenson *et al*. (1998) suggested, in a study of the regional genetics of Nassau grouper, that the occupation of particular spawning aggregation sites might be a learned behaviour and not genetically programmed. They offered this possible explanation for the observation that spawning aggregations, once depleted, appear not to recover via recruitment from other areas. In particular, the results of their analysis using microsatellite markers revealed no conclusive evidence for stock separation among four spawning aggregations in Belize. These results imply that spawning aggregations are not maintained by self-recruitment alone and that larvae from other sources may be mixing at aggregation sites to maintain genetic homogeneity.

The size range of specimens documented in return migration events was 26 - 55 cm FL. The most notable migration event was the movement of a tagged specimen (36 cm FL) from North Rock on the northern boundary of the Bermuda reef platform (Figure 1) to the aggregation site, a straight line distance of >20 km, in a maximum of seven days. This feat was duplicated a further five times by different specimens, some with different release dates, in 1994 and 1995 (Table 3). In comparison, Burnett-Herkes (1975) found that the maximum dispersion distance by tagged red hinds, when released at a spawning aggregation site, was 15 km with a time at liberty of four weeks. In Puerto Rico, Sadovy *et al.* (1994) recaptured a tagged red hind at a spawning aggregation site after two years at liberty. It had migrated a distance of 18 Km from its original tagging site. Also notable in my study were two return migration events which took place from a release site (R6) on the southern edge of the reef platform (Figure 1) covering approximately the same distance (> 20 km) as above, with the return of one specimen in 24 days (Table 3). Return migration events from release sites closer to the aggregation site further confirm what is clearly directed movement back to the aggregation site with specimens moving distances of 2 - 6 km in 3 - 5 days (Table 3). Zeller (1998) documented a maximum distance between established home ranges and spawning aggregation sites of 5.2 km but with total spawning movements back and forth for individual fish of over 17 km.

The recapture of displaced specimens at the aggregation site outside of the spawning season is more difficult to explain. One specimen released in August 1994 at North Rock was recaptured three months later in November at the aggregation site (Table 3). This same specimen (#184) was displaced again to a different release site and homed a second time outside of the spawning season. One possible explanation is that this specimen included the aggregation site as a part of it's normal home range. The tagging conducted to date has not permitted the estimation of catchment areas in relation to spawning aggregation sites such as those provided by Zeller (1998). Additional directed tagging studies will need to be conducted to elucidate various elements of the movement dynamics of this aggregating grouper.

Table 3. Summary of return migration events to the EPA spawning aggregation site by tagged red hinds during 1994-95 when released at various locations distant from the site (see Figure 1). Distance travelled was measured as a straight line between release site and aggregation site using GPS coordinates. See text for details.

Tag No.	Size at Release (cm FL)	Sex (if known)	Release Site and Date	Maximum Transit Time (days)	Distance Travelled (km)
37	43.5		R4 - 8 Jul '94	333	6.8
83	55.0	F	R1 -31 May '94	28	20.1
85	32.5		R1 -31 May '94	16	20.1
98	40.0		R3 - 4 July '94	14	2.1
	40.0		R4 - 21 July '94	17	6.8
99	50.5		R2 - 24 Jun '94	5	2.3
109	36.0		R2 - 21 Jun '94	3	2.3
	36.0		R2 - 24 Jun '94	4	2.3
	36.0		R1 - 30 Jun '94	7	20.1
111	40.0	F	R2 - 24 Jun '94	4	2.3
121	50.0		R2 - 22 Jun '94	9	2.3
124	46.0		R2 - 22 Jun '94	12	2.3
137	47.0		R2 - 24 Jun '94	10	2.3
144	26.0		R1 - 30 Jun '94	34	20.1
155	39.0	F	R3 - 1 Jul '94	11	2.1
165	45.0	F	R2 - 4 Jul '94	31	2.3
183	53.5	M	R4 - 8 Jul '94	10	6.8
184	33.5	F	R4 - 21 Jul '94	14	6.8
	34.0		R1 - 5 Aug '94	96	20.1
	34.5		R4 - 10 Nov '94	125	6.8

Table 3. (continued)

Tag No.	Size at Release (cm FL)	Sex (if known)	Release Site and Date	Maximum Transit Time (days)	Distance Travelled (km)
211	42.4	F	R4 - 8 Jun '95	5	6.8
216	34.5		R4 - 8 Jun '95	30	6.8
219	34.8		R4 - 8 Jun '95	4	6.8
	35.2		R6 - 13 Jun '95	7	6.3
221	29.6		R4 - 8 Jun '95	26	6.8
237	46.0		R4 - 8 Jul '95	342	6.8
239	46.0		R6 - 16 Jun '95	24	20.3
247	58.2		R6 - 16 Jun '95	360	20.3
255	54.5		R1 - 27 Jun '95	14	20.1

The application of these findings to fisheries management provides a firm basis for initiating or continuing measures to conserve red hind spawning stock biomass. The strong site fidelity demonstrated in this study makes individual aggregations vulnerable to depletion. Seasonal closures of spawning aggregation sites can be effective in maintaining populations by significantly restricting access to the resource when catchability is high. Beets and Friedlander (In press) demonstrated a significant increase in mean size and an improved sex ratio in their evaluation of the effects of a red hind aggregation closure in the US Virgin Islands. My study confirmed that the existing seasonally closed area at the east end of the island (EPA) contains at least one active red hind aggregation site which was used for at least three consecutive years (1993-95) during the summer spawning period. Long term monitoring of these aggregation sites is desireable in order to evaluate the effects of seasonal closures which can be used in conjunction with other fishery management measures to maintain viable grouper populations.

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