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Effects of off-road vehicles on reproductive success of pine snakes (*Pituophus melanoleucus*) in the New Jersey pinelands

Joanna Burger · Robert T. Zappalorti · Michael Gochfeld · Emile DeVito

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Abstract Considerable attention has been devoted to the effects of people and their vehicles on birds and mammals, but possible effects on reptiles in populated areas have received less attention. Moreover, the effects of human activities on reptile reproductive success itself has been harder to demonstrate. This paper examines the effect of management of off-road vehicles in New Jersey's pinelands on the reproductive success of pine snakes *(Pituophus melanoleucus)* from 1986 to 2005. We used the percentage of snakes in each hibernaculum that were young of the year (hatchlings) as an indicator of reproductive success, and compared this percent for five hibernacula that were in an area with varying degrees of off-road vehicle (ORV) disturbance, with 12 hibernacula in areas with no ORV disturbances (reference sites). This percent took into account differences in absolute numbers from one location to another, and over time due to hibernacula destruction (by people or predators) and natural variations (food supply). The ORV pressure in the pinelands is intense because it lies within the most densely populated urban area in the United States. Although the number of snakes in the reference hibernacula varied over the years from 46 to 63, the percent of young in these hibernacula did not vary significantly over the 20 year period (21–29%). In contrast, the percent-young in the disturbed sites differed significantly in years without ORV disturbance (28%) compared to

J. Burger
Division of Life Sciences, Rutgers University, Piscataway, NJ 08854-8082, USA

J. Burger (✉) · M. Gochfeld
Center for Urban Restoration Ecology, Rutgers University, New Brunswick, NJ 08903, USA
e-mail: burger@biology.rutgers.edu

R. T. Zappalorti
Herpetological Associates, Inc, Plant and Wildlife Consultants,
575 Toms River Road, Jackson, NJ 08527, USA

M. Gochfeld
Environmental and Occupational Health Sciences Institute,
UMDNJ-Robert Wood Johnson Medical School, Piscataway, NJ 08854, USA

E. DeVito
New Jersey Conservation Foundation, Far Hills, NJ 07931, USA

those with ORV disturbance (15 and 16%, $P<0.01$). Further, there were no differences between the percent of young in the reference sites and those in the disturbed site in years without ORV disturbance. ORV disturbance ceased only with the creation of large dirt berms coupled with fences that could not be easily broken. These data indicate the importance of having detailed population data on pine snakes in hibernacula, on ORV use (or indications of such use), and of managing ORV use to protect sensitive populations. Maintenance of healthy pine snake populations in urban areas may require continued adaptive management.

Keywords Human disturbance · Off-road vehicles · Reptiles · Snakes · Hibernating · Urban wildlife · State parks

Introduction

One of the important questions in understanding urban ecosystems is determining how people affect wildlife, and what mitigation or management actions can ameliorate effects. While much attention has been devoted to examining the effects of people on wildlife in wilderness and semiwilderness areas (Knight and Gutzwiller 1995), there is relatively little research in urban and suburban areas, and in areas that are heavily impacted by people (Rees 1997). Urban studies with wildlife mainly deal with fragmentation (Dowd 1992; Jokimaki and Suhonen 1993), effects of pedestrians on forest-nesting birds (Fernandez-Juricic 2000), of cars on foraging birds (Keller 1991), on road mortality in turtles (Haxon 2000), and of human disturbance to snakes in rockpiles (Goldingay and Newell 2000). Moreover, most of the studies of these effects of human disturbance deal with short-term effects, and not with observable effects on reproductive success, recruitment, or fitness. Further, in many of the studies with reptiles, adverse effects were attributed to general human disturbance, and not to a specific human activity that was amenable to management to reduce these effects (but see Burger 2001). Partly this results from the diversity of human activities that are common in urban areas, making isolation of one factor difficult.

In this paper we examine the effect of off-road-vehicles (ORV) on reproductive success of pine snakes *(Pituophus melanoleucus)* in the New Jersey pinelands from 1986 to 2005. These results are part of a larger study of the hibernation behavior of pine snakes in the New Jersey Pine Barrens beginning in 1986, concentrating on hibernacula structure, predation on hibernating snakes, and philopatry of the snakes (Burger et al. 1988, 1992, 2000). Our overall objective is to understand the factors that affect reuse of the same hibernacula, condition and survival of the snakes, and the effect of human disturbance on hibernacula use. The study was not initially designed to examine the effect of ORV on pine snakes, but rather to examine the ecology and behavior of hibernating snakes. However, ORVs are one type of human activity and the long-term data can be used to examine the effects of varying types of human activity. The value of targeted experiments and observations to management is particularly critical for mitigating the effects of human disturbance (e.g. Goldingay and Newell 2000).

Population stability is a function of reproductive rate, recruitment, and survival, but these traits are difficult to measure in pine snakes because they nest underground, are cryptic, and are difficult to locate when they are above ground. We used the percent of young in each hibernaculum as a measure of overall reproductive success, since for young to survive their first year they have to successfully reach a hibernaculum where they can spend their first winter. Using the percent young (expressed as the percent of snakes in a hibernaculum that were young of the year) corrected for population changes due to weather, food, and predators. We compare this percentage in hibernacula with and without ORV activity, and for areas with ORV activity, with and without management. Our objective was to examine whether management could diminish the impact of ORV activity. Over the years we employed an adaptive management approach. For example, we increased the type and strength of barriers when we observed that previous barriers were unsuccessful in deterring ORVs.

New Jersey pine snakes are isolated in the pinelands from others of the same species that breed from the Carolinas southward, and unlike their conspecifics elsewhere, they dig their own nests and exhibit a high degree of philopatry to these sites (Burger and Zappalorti 1986, 1988, 1991, 1992). They overwinter in hibernacula that they dig themselves or modify from old mammal burrows (Burger et al. 1988). Once they are 1–2 m below the surface, they excavate tunnels in the sand, and curl up inside chambers, one to three snakes together. While in the hibernacula they are vulnerable to a range of predators, and exhibit some defensive behaviors when excavated (Burger et al. 1992, 2000). The young hatch in late August to early September, and must find their way to a hibernaculum, before the freezing temperatures of November, by following the scent trails of adults (Burger 1989a, 1991b, 1998). Pine snakes are listed as threatened by the State of New Jersey. Pine snakes nest in the open sand, laying their eggs in shallow underground burrows that they excavate. Once the young hatch, they emerge and within two weeks seek food, and then search for a hibernaculum to spend the winter. ORVs can impact reproductive success by churning up the sand and destroying the eggs, as well as injuring the young below ground and after they emerge. The number of young that reach the hibernacula is an indication of overall reproductive success (and recruitment) since unless a hatchling reaches a hibernacula they will freeze over the winter.

While the pinelands of New Jersey is protected by law, it is a reserve where residential development is incorporated into the pine barrens ecosystem. New Jersey has the highest human population density (436/km^2) in the United States, and is surrounded by the metropolitan areas of New York and Philadelphia, in the busy Boston–Washington corridor. The pressures in the pinelands for development and human activities (such as ORVs) is very intense.

Finally, most attention has been devoted to understanding disturbance impacts on birds (Burger 1986, 1991a; Pfister et al. 1992; Roberts and Evans 1993; Rodgers and Smith 1995; Rodgers 1997; Carney and Sydeman 1999) and mammals (Blane and Jaakson 1994; Knight and Gutzwiller 1995; Knight and Temple 1995). Some attention has focused on reptiles, particularly on disturbance to nesting turtles and lizards (Schlaepfer 2003; Jessop and Hamann 2004; Moore and Seigel 2006), effects on basking or foraging reptiles (Burger 2001; Parent and Weatherhead 2000; Goldingay and Newell 2000), effects of roads (Garber and Burger 1995; Gibbs and Shriver 2002), effects of livestock on nesting reptiles (Homyack and Giuliano 2002; Semlitsch and Bodie 2003), and the effect of forest management on reptile assemblages (Brown 2001; Russell et al. 2002). The lack of studies with snakes is largely because of their solitary or secretive nature and the difficulty of observation.

Materials and methods

Study areas All studies were conducted under appropriate permits issued by the New Jersey Department of Environmental Protection and were approved by the Rutgers University Institutional Animal Care and Use Committee. We studied the behavior of pine snakes in hibernacula in the New Jersey Pine Barrens in Burlington and Ocean counties. The hibernacula we excavated were located in Bass River State Forest, on private land, and on other state lands (Wildlife Management Areas). The management of these areas differs.

Although the operation of ORVs is prohibited by law on State of New Jersey conservation lands, in practice, ORVs are not restricted on State Forest or Wildlife Management Areas due to a nearly complete lack of law enforcement personnel and resources. Land managers can attempt to restrict ORV use in places with endangered or threatened species, if enough attention is brought to an issue and if public/private partnerships form to bridge the funding shortfalls. The ORV public generally avoids private lands for fear of trespass charges, and there was no ORV use on any of the private lands with hibernacula. In general, ORV activity on state lands is heavy from May through September, and heaviest in June through August, but also occurs all year. Groups of ORV owners often used one of the hibernacula sites (a wide open field) for meeting, eating, and running races. ORV activity from June through September directly disturbs females who are digging nests, eggs in the nest, and emerging and hunting hatchlings.

Hibernacula are generally located in relatively exposed sandy areas dominated by pitch pine (*Pinus rigida*) and small oaks (*Quercus* spp.). Exact locations are not given because of the threat of poaching; pine snakes nest near hibernacula, and in some years nearly 40% of nests have been poached (Burger et al. 1992).

Protocol We dug up the same hibernacula each year (late February to mid March, depending upon weather and snow cover), removed all snakes for identification, marking, and measuring, and replaced them in their reconstructed hibernacula within a day. All snakes encountered were marked with passive-integrated transponder (PIT) tags which were read on subsequent encounters using a radiofrequency wand (Elbin and Burger 1994).

After all snakes were removed, we rebuilt the hibernacula, reconstructing a main underground chamber using cement blocks for walls, plywood or sheet metal for a roof, and hollowed cement blocks laid side to side to create a permanent tubular entrance to the surface. The blocks were offset slightly to ensure that the hole was small enough to prevent foxes (*Vulpes vulpes*) and skunk (*Mephitis mephitis*) from entering. The entrance was further camouflaged by leaves, twigs and branches to deter human poachers.

In the 20 years of our work, only four skunks and a short-tailed shrew entered the rebuilt hibernacula by making their own entrances elsewhere, and seven hibernacula were partially or completely dug up by poachers. In spite of our annual disturbances, and that of the occasional mammalian predator, the pine snakes continued to use the same rebuilt hibernacula. There was some shifting among hibernacula, and there was natural variation in the number of snakes using these hibernacula each year.

Each year we excavated from seven to seventeen hibernacula, each containing from zero to 32 snakes. While we could have searched for new hibernacula, we did not because we had not necessarily intended to continue the study so long and searching for new hibernacula was extremely time-consuming. It required searching for snakes basking in the autumn, use of drift fences, or radio-tracking. At each hibernaculum we carefully uncovered the opening, and dug with shovels until we reached about 0.8 m. or the top of the man-made chamber. Once the roof of the chamber was uncovered, and any snakes were removed, we proceeded with intense care to locate tunnels leading to hibernating snakes. We probed the tunnels with a narrow rod that served as a guide so that we did not lose them. All shoveling was done very slowly, often with hand trowels. In our 20 years of work with the hibernating snakes we never injured one.

In this paper we report the number of snakes (hatchlings and older snakes, dead and alive) that were found in all study hibernacula, and compare the percent of young (of total snakes) in hibernacula of an area used by off-road-vehicles, with all other areas. During the 20 years of our study, there were five hibernacula in one area used by ORVs, and 12 in non-

ORV areas. The 12 in non-ORV areas (hereafter referred to as reference sites) were largely in flat pitch pine habitats without a large open expanse for ORV activity. The ORV hibernacula (Ed's Place) were located in an open expanse that was once a large farm field.

In the early 1990s we lost a number of our hibernacula to residential development, predators, and management for other wildlife values (deer production). Further, the number of snakes varied from year to year, no doubt due to some snakes using other hibernacula and to natural differences in reproduction and survival. Therefore, in this paper we use the percent of young in the hibernacula as an indication of reproductive success. We compared the percent of young in the hibernacula with ORV activity with that of the non-ORV sites using a Contingency Table X^2 test. We also compared the ORV site with and without management.

Results

Management The ORV site (Ed's Place) in Bass River State Forest is an abandoned farm field, accessed by a sand driveway through pitch pine. During our study the buildings deteriorated and were burned by vandals. With time, more and more ORVs began to use the open field, churning up the sand and destroying nests.

In the late 1980s when we noticed an increase in the number of ORV, the Bass River park rangers posted the land as "off limits to motorized vehicles." However, the ORVs continued to use the site, so in 1993 after we found no hatchlings in these hibernacula, a gate was erected at the sand roadway entrance by Bass River rangers, in conjunction with the New Jersey Endangered and NonGame Species Program (the agency responsible for state threatened/endangered species). This worked for two years, but the gate was then broken by ORVs and other vehicles simply went through the forest to get there, creating new "roads" to access the party site.

In 1998, following another severe decline in hatchlings, the gate was replaced, and a one foot high soil berm was placed on either side of the gate to discourage ORVs. Since this was breached over the next 2 years (although to a lesser degree than previously), the New Jersey Endangered and Non-game Species Program and the New Jersey Conservation Foundation built and maintained a stronger, more secure gate and built higher (3.5 m) and longer (75 m) berms, making it impossible for ORVs to enter Ed's Place without detouring through dense pine woods. ORVs were thus successfully excluded after 1998, except for a brief period in 1999 when the berm was breached.

Snake populations in the hibernacula From 1986 to 1990 the number of snakes encountered in the hibernacula increased (Fig. 1). However, from 1991 to 1995 predators, development, and management actions resulted in the destruction of nine hibernacula. Three were on private property and were destroyed by the owners, one was destroyed by state wildlife management personnel who disked it up to enhance habitat for deer hunting, and the rest were destroyed by fox or skunks that dug into the burrows. The maximum number of snakes in the destroyed hibernacula was 23. From 1992 until 2002 the number of snakes remained relatively constant (25–40), it declined in 2003 (the previous year was very dry), and increased in 2004 and 2005 (Fig. 1).

Percent of young The percent of young in hibernacula varied over the 20 years (Fig. 1). We divided the hibernacula into ORV and reference site hibernacula, and divided the ORV

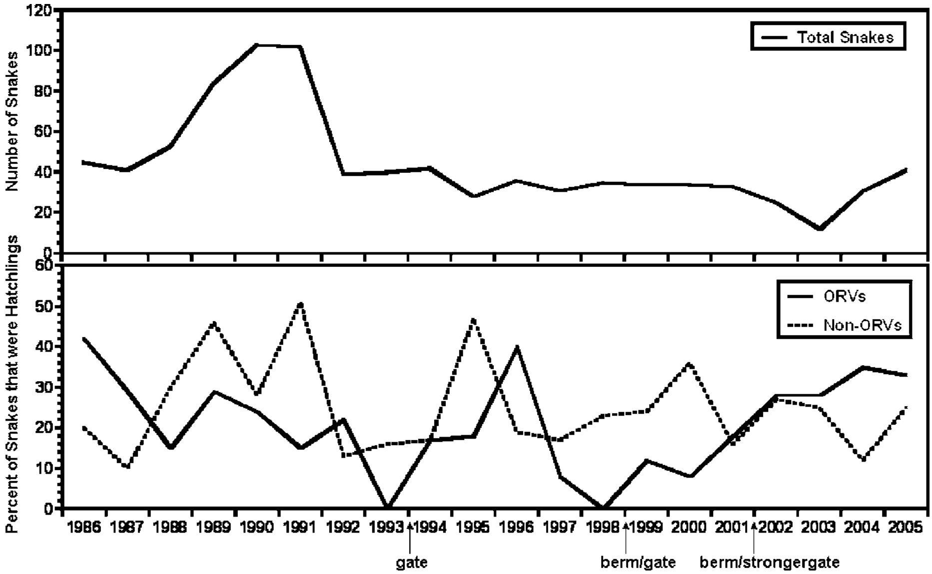
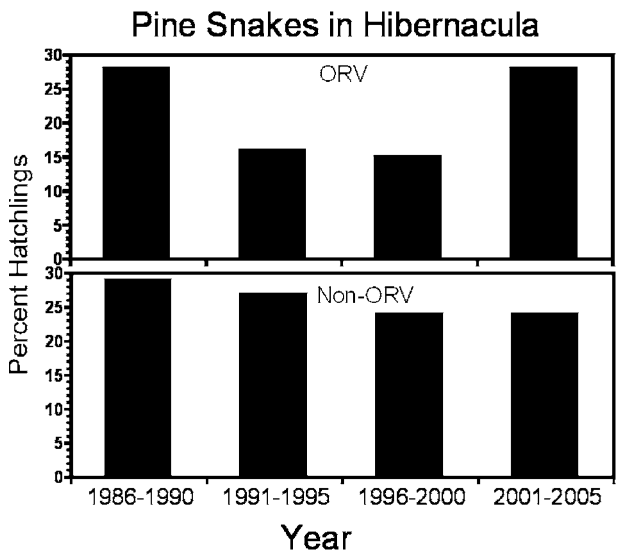


Fig. 1 Total number of pine snakes in hibernacula from 1986 to 2004 (N=17), and percent hatchlings in the off-road-vehicle hibernacula (N=5) and the reference hibernacula (N=12). Management actions also shown

hibernacula into periods of management and lack thereof. There were no significant differences in the percent of young in hibernacula in the four time periods examined for the non-ORV hibernacula (X^2 tests). However, there were significant differences in the percent of young in the ORV hibernacula when 1986–1990 and 2001–2005 (years with low ORV activity) were compared with 1991–2000 (years with high ORV activity, X^2=8.88, P<0.01, Fig. 2).

Fig. 2 Average percent of hatchlings in hibernacula exposed to off-road-vehicles (*top*) and reference hibernacula (*bottom*) for different periods from 1986 to 2004



Discussion

The results of this study indicate that: (1) pine snakes continue to use hibernacula despite our yearly disturbance, (2) some hibernacula are destroyed by predators, poachers, and habitat loss due to development, (3) the number of snakes in hibernacula vary temporally, (4) the percentage of young in hibernacula (an indication of reproductive success in the previous summer) did not vary significantly from 1986 to 2004 in hibernacula in areas without ORVs, (5) the percentage of young in hibernacula in an ORV area was significantly higher in years without ORV activity compared to years with ORV activity, (6) the percentage of young in the ORV area in years without ORV activity was similar to that of non-ORV areas, and (7) active and aggressive management decreased the ORV activity, allowing for increased reproductive success. These data clearly indicate the importance of monitoring data, and of active management to keep ORVs from snake nesting and hibernacula areas. Several aspects of this research require discussion, including natural variation in the number of snakes (and the percent of hatchlings) in hibernacula, the effect of ORVs on snakes, the importance of management on preservation of healthy pine snake populations, and methodological issues.

Population dynamics The data presented in Fig. 1 clearly indicate that the total number of snakes in hibernacula varies temporally, which may reflect natural variations in snake numbers, or variation in the use of particular hibernacula. That is, some snakes switch hibernacula from one year to the next, and return in subsequent years (Burger and Zappalorti, unpublished data). Because of this variation, we used the percent of young as an indication of the effect of ORVs on reproductive success (see below).

The number of snakes encountered, however, also reflects the number of hibernacula we followed. That is, the number of hibernacula we examined varied from seven to seventeen because of the disappearance of hibernacula due either to predators or destruction. During the 20 years of this study, we lost some hibernacula because either fox or skunk dug them up and the snakes no longer used them, and to destruction by plowing and bulldozers. Thus, the overall decline in the total number of snakes (top of Fig. 1) in the early 1990s was due to a decrease in the number of hibernacula we examined (with their associated snakes). Although the number of hibernacula varied during this study, we have no a priori reason for assuming that natural factors operated to bias our results. This is particularly true given that there were no significant differences in the percent of hatchlings among non-ORV hibernacula. Secondly, survival and reproductive success clearly varied over the years due to natural causes, such as poor food years (which can lower both clutch size and survival of offspring), or inclement weather (heavy rains or cold weather that delays nesting). These factors (weather, food), however, do not affect the analysis, since the ORV and non-ORV hibernacula experienced the same weather and food conditions.

It should also be noted that for the purposes of this study, yearly variations in weather conditions and food supplies do not impact our results because we were comparing ORV and non-ORV exposed hibernacula for the same years. Thus, both ORV and non-ORV hibernacula were exposed to the same yearly variations due to weather, food, or other variables (such as predator pressure).

Finally, reaching a hibernaculum does not guarantee survival of hatchlings over the winter. Young hatchlings are vulnerable to shrew *(Blarina brevicauda)* predation and to being crushed by larger snakes; a 45 g hatchling is no match for a 1,200 g adult (Burger et al. 1992). All pine snakes in hibernacula are also vulnerable to skunk and fox predation. Further, hatchlings sometimes start to leave the hibernacula before the weather is warm enough, and we have found hatchlings frozen near the surface.

ORV Effects ORVs have a number of possible effects on nesting snakes. At Ed's Place, females normally excavated nests in the middle of the open field where the eggs would have maximum sun exposure. In other work we have shown that sun penetration is essential to providing the eggs with sufficient warmth so that the young do not experience behavioral deficits. We found in laboratory experiments that young hatched at low incubation temperatures suffered a number of behavioral deficits in their ability to locomote, find and eat prey, and avoid predators (Burger et al. 1987; Burger 1989b, 1991b). ORVs, then, could have four direct effects on reproductive success of females: (1) females could be killed while digging nests in the open field, (2) if females continued to nest in the open, then their nests would be churned up by ORVs, and the eggs or young killed, (3) if females moved to the edge of the field or into the forest where there was no ORV activity, hatching success would be lowered or young might hatch with behavioral deficits, resulting in their being less likely to find food and a hibernaculum and survive the winter, and 4) hatchlings wandering over the open field in search of food or a hibernaculum would be killed by ORVs. Bonnet et al. (1999) reported that young-of-the-year (hatchling) snakes were killed primarily in the period immediately after hatchling while they are dispersing.

In the case of pine snakes, the hatchlings could be run over by ORVs when they are leaving their nests, when their movement is slowed or they are temporarily trapped in deep ORV wheel ruts, when they are searching for food, and when they are searching for hibernacula. They also may indirectly fall prey to hawks or other predators because of lack of cover and the pure white sugar sand created by intense ORV activity. Undisturbed, but open pine barrens develop a mottled white, grey and black pattern that is broken by lichens, small bushes and herbs.

Active and aggressive management was required to keep the ORVs from Ed's Place. It is so remote that rare patrolling by park personnel was not sufficient to keep ORVs out. Signage was not successful as a deterrent to ORVs at all, and a normal gate had success only for 2 years. Further, a shallow berm had only minor effect. Ed's Place turned out to be a preferred habitat for ORVs as well as for Pine Snakes, and both continued to try and use the field despite the presence of the other. Only a relatively tall and long berm, coupled with a gate that had cement footings and a lock that could not be cut or broken, succeeded in keeping the ORVs out of Ed's Place. Once ORVs were no longer present, the percentage of young in hibernacula increased to the level it had been when Ed's Place was not used by ORVs, and to the levels found in the other non-ORV hibernacula. The data clearly indicate the importance of monitoring data, of monitoring ORV activity, and of managing to reduce conflicts between ORVs and snakes.

While it is possible to document direct effects of ORVs on hatchlings (we have observed them dead and squashed in ORV tracks), it is difficult to derive survival data. Thus, we used survival of hatchlings to reach hibernacula as a measure of effects. We feel by using the percent of young in hibernacula we can partly control for this variation. Thirdly, our digging up the snakes may be a disturbance. We respond to this by noting that the hibernacula that disappeared did so due to predators, residential development, and habitat loss. Further, the same marked snakes continued to use the same hibernaculum from year to year (Burger and Zappalorti, unpublished data). Finally, one might argue that it is the hibernacula that are disturbed by ORVs, and not the nesting snakes. This appears not to be the case because the sand around the hibernacula at Ed's Place was not disturbed, and the hibernacula were at the edge of clearings or near the trunks of big trees, places avoided by ORVs.

In conclusion, this 20 year data set indicates that there was natural variation in the number of pine snakes using particular hibernacula, that when averaged over 5 year periods, the percent of young in hibernacula (our measure of breeding success) remained relatively constant, and that hibernacula exposed to ORVs have a lower percent of hatchlings than those not exposed to ORVs. Only aggressive management that kept ORVs from the nesting/hibernaculum sites resulted in an increase in the percent of young to pre-disturbance levels.

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