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Diet composition and consumption rate in round goby (*Neogobius melanostomus*) in its expansion phase in the Trent River, Ontario

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Abstract We assessed density, gut fullness and prey composition of round goby (*Neogobius melanostomus*) from three areas in the Trent River (Ontario) representing areas of initial introduction and subsequent expansion. Round goby had been present at the area of original introduction since 2003, and by 2007/2008, their range had expanded upstream and downstream into the outermost reaches sampled in the study. Catch per unit angling effort in nearshore sites indicated that round goby density in the area of original introduction was more than double their density in the upstream expansion area and nearly three times the density in the downstream expansion area. Gut fullness index was lower in gobies from the area of original introduction than for those at the upstream and downstream edges of their expanded range. The most dramatic difference in diet composition was with dreissenids, where large gobies (≥70 mm) occupying the area of original introduction had almost no dreissenid biomass in their guts, whereas dreissenids were the predominant prey type in gobies occupying the two expansion areas. Post-hoc zebra mussel density in the area of original introduction was an order of magnitude lower than in the two expansion areas which, combined with the differences in stomach fullness and prey composition, suggest that local, density-related reduction of this prey type was occurring in the river.

Keywords Dreissenid · Invasive species · Macroinvertebrate · Range expansion

Introduction

Understanding the invasion dynamics of non-native species is very important in both scientific and practical terms (Alcaraz et al. 2005; Garcia-Berthou 2007). Current and potential rate of spread, predicting habitats prone to future invasion, and understanding impacts on ecosystems are all areas of knowledge potentially enriched by the study of invasion dynamics. Both life history traits, as well as tolerance of environmental change are known to be strong predictors of invasion success in non-native fish species (Rosecchi et al. 2001).

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The round goby (*Neogobius melanostomus*) is one of the most ecologically significant aquatic invasive species in the Great Lakes basin. Since its arrival in 1990, it has spread throughout the Great Lakes and is also moving into inland waterways (Jude et al. 1992; Charlebois et al. 1997). The round goby is capable of inhabiting a broad range of environments, in part because of its tolerance of temperature and salinity conditions (Charlebois et al. 1997). It also consumes a wide variety of prey items, including mussels (primarily *Dreissena* spp.), amphipods, chironomids, cladocerans, dragonflies, crayfish, mayflies, isopods, fish eggs, and larvae (Corkum et al. 2004). Its highly opportunistic prey consumption pattern is an important factor in its success as an invasive species (Barton et al. 2005). However, food resources can become limiting even for the most opportunistic fishes when fish density reaches a certain point, and this can occur with the round goby, despite its major prey items (the invasive zebra and quagga mussels, *D. polymorpha* and *D. burgensis*, respectively) occurring at very high densities over most of its North American range (Barton et al. 2005).

Species invasions are dynamic, and areas that do not contain the invasive species at one point in time can later be inhabited by large numbers of this species as the population expands into new territory. Population density can also change over the course of an invasion, particularly in recently-invaded areas as the population has time to build (Bøhn et al. 2004). Theoretically, the edges of the goby's range should contain fewer individuals, whereas at the center of its range where the species has been established for the longest period of time, the population should have a higher density. Such differences in round goby density have been demonstrated along the shoreline of Green Bay (Lake Michigan), and in the Bay of Quinte (Lake Ontario) between early and later-occupied sites (Lederer et al. 2008; Taraborelli et al. 2009).

The objective of our study was to compare the density, food consumption rate and diet composition of round gobies that occupy an area within a river where the species was originally introduced with those living at the upstream and downstream edges of its expanding range. Based on the hypothesis that round gobies impact prey resource availability (Barton et al. 2005; Krakowiak and Pennuto 2008; Lederer et al. 2008), we predicted that round gobies occupying the central area near the original introduction would consume a lower quantity of prey than those occupying the upstream or downstream edges of the range expansion. We also hypothesized that diet composition would differ between gobies occupying the central area and those occupying the edges of expansion. Finally, we predicted that the consumption of dreissenids, amphipods, and chironomids by gobies in the central area would be lower than at the edges of expansion, as these invertebrates are typically the predominant prey types consumed by the round goby (see Ghedotti et al. 1995; French and Jude 2001; Diggins et al. 2002), and their density could be affected by high goby predation rates over an extended period of time.

Methods

The study was conducted in the Trent River in central Ontario. The river is part of the Trent-Severn Waterway, a heavily dammed system with multiple locks that connects Georgian Bay (Lake Huron) in the northwest to Lake Ontario in the southwest. The round goby was first found in the river near the lock at Hastings, Ontario (44° 18′ 38′ N, 77° 57′ 10′ W) in 2003 (unpublished data, Ontario Federation of Anglers and Hunters), and it is presumed that round goby were transferred from Lake Ontario by a bait bucket introduction. Preliminary seining in 2007 indicated that round gobies in the littoral zone were very abundant from approximately 0.8 km downstream to 0.2 km upstream of Lock 18, suggesting the species had spread into this area near the time it was initially introduced. We therefore used this stretch of river as to represent the area of first introduction (hereafter referred to as the central area).

Since 2003, the round goby has greatly expanded its range in the river. To locate the edges of its distribution, intensive surveys were conducted at the beginning of this study, using angling and seining. Round gobies were located as far as 16 km upstream from the area where they were first found (Fig. 1). However, the upper 12 km of its upstream distribution contained only isolated individuals and a few small offshore aggregations, and therefore, the area within 2 km of the edge where round goby have been present for less than 2 years was treated as the upstream area of range expansion for the purpose of this study.

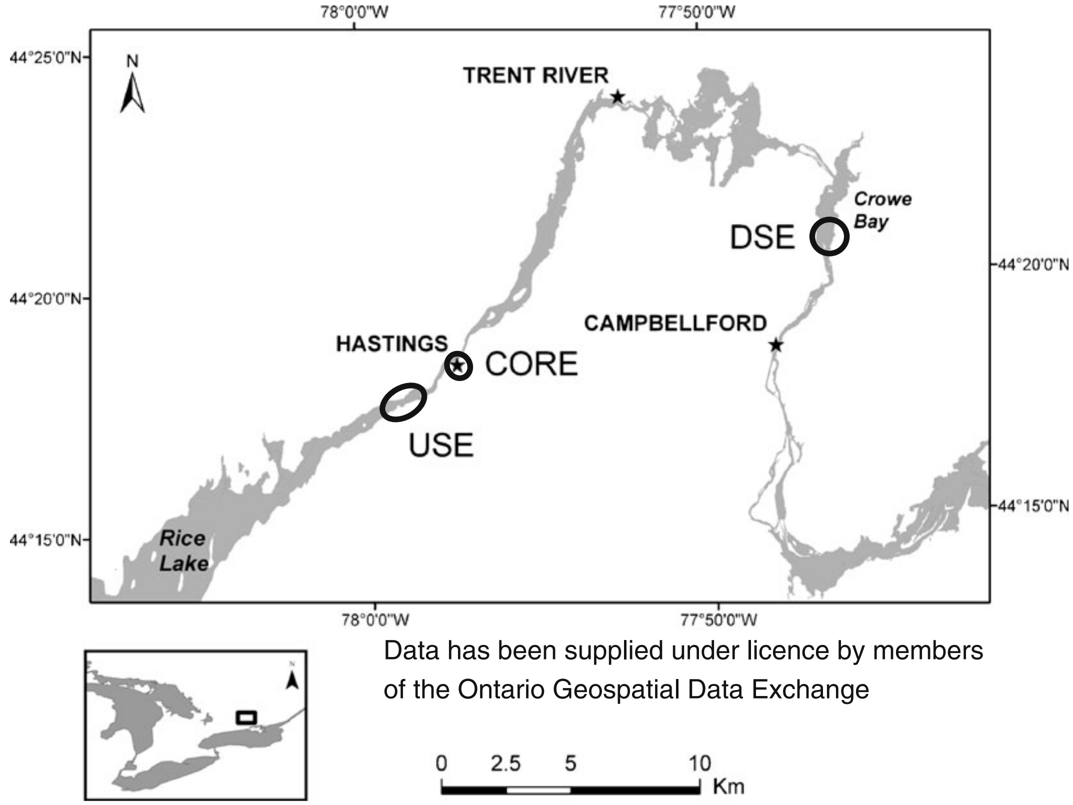

Fig. 1 Location of the three study areas (*open circles*), defined as the area of original introduction (CORE), and the outermost areas of upstream and downstream range expansion (USE and DSE, respectively) in the Trent River, Ontario

Downstream expansion of their range has occurred much faster, despite the presence of Lock 17 and the dam at Healey Falls (44°22′10′ N, 77°46′28′ W). By 2008, round gobies were present in Crowe Bay, about 30 km downstream of Hastings. Aggregations were found as far downstream as Crowe Bay; therefore, this area was treated as the downstream area of range expansion.

Round gobies were collected from the littoral zone of the central, upstream and downstream areas during four periods (10–11 June, 23–24 June, 21–24 July and 6–7 August) in 2008. To minimize potential habitat effects on goby consumption patterns in the areas being compared, samples were collected from sites that contained sparse macrophyte cover, a mixture of sand, gravel and rock substrate, and low water velocity. Four sites were sampled within each study area and time period, and different sites were used for each time period. Collections were made during daylight hours (09:00–15:00 h) using a 15× 2 m bag seine with a 6.4 mm mesh. Gobies were separated by sex, euthanized using MS-222, kept on ice, and stored frozen. Fish were later defrosted, measured for total length (TL, nearest mm), and wet-weighed (nearest 0.01 g). The entire digestive tract of each fish was removed and stored in 70% ethanol for subsequent prey content analysis.

The contents of each round goby digestive tract were removed and weighed (wet weight, nearest 0.01 g), before being spread out to a uniform depth in a gridded Petri dish. As none of the digestive tracts of gobies assessed in the study were empty or lacked identifiable prey, all gobies examined were included in gut content analysis. Prey items were identified and categorized as either dreissenids (zebra and quagga mussels), amphipods, chironomids, other benthos (water mites and dragonflies, mayflies, phantom midges, aquatic beetle larvae, free-living nematodes, and caddisflies) or zooplankton. Unidentifiable prey were excluded from diet composition analysis. The relative volume of each prey type as a percentage of the total gut contents of each fish was estimated and gut fullness (prey weight as a percentage of total wet weight of the individual) was used as an indicator of consumption rate (e.g., Hollingsworth and Connolly 2006).

Angling trials were used to assess the relative abundance of round goby in the three sampling areas. Angling sites were selected at random from within the three areas as part of a larger study of goby density in the river, but for the present study, only sites with a mix of gravel and rock, minimal macrophyte cover, and depth <3 m were used in order to make them comparable to sites where gobies were collected for stomach content analysis. Each trial involved 20 min of angling by two individuals in a fixed 1.5 m^2 area delineated by a floating foam arena attached to the anchored fishing boat. Gobies were angled with lightweight rods with small lead weights attached to the line along with, a size-20 hook with a small scented, plastic maggot. Angling trials were conducted from May to September, and took place between 9:00 and 15:00 h. A total of 59 sites (27, 22 and 10 within the central, upstream and downstream areas, respectively) were used for this part of the study. Site locations were identified with a GPS to ensure that each site was sampled only once.

To compare the density of round gobies inhabiting the central area with those inhabiting the upstream and downstream areas, we first compared angling catch per unit effort of these areas with a Kruskal-Wallis test, as CPUE data could not be normalized for parametric analysis. This was followed by paired area comparisons when the initial test was significant. The same procedure was used to compare the contribution of major prey items consumed by round gobies in the central area with that of gobies occupying the upstream and downstream areas.

Gut fullness (Gut Fullness Index; GFI) data (all prey combined) were normalized for parametric analysis by $\log_{10}$ (GFI+1)-transformation. A two-way fully factorial ANOVA was used to test for area and sampling period effects, and a Tukey HSD test was subsequently employed to compare gut fullness of gobies from the central area with those of the upstream and downstream areas.

Relative condition factor (K_n) was used as a rough measure of body condition (Wootton 1998). Individual total weight was divided by the weight for each individual as predicted by total length, based on the length weight relationship developed from gobies collected from the Trent River. The same statistical model was used for condition factor data as with gut fullness (two-way ANOVA using period and sampling area).

To explain the major differences in goby prey consumption between the central and edge areas (see results) a post-hoc dreissenid assessment was conducted in the three study areas in April 2009. Samples were taken from the same sites used to collect round gobies for stomach content analysis. Randomly selected rocks were removed from approximately 60 m of shoreline from 0.5 m to 1 m of water, and their length, width and height measured to estimate the surface area. All live dreissenids were removed from each rock, pooled by area, kept in water and transported to the lab for analysis. A 15% sub-sample by weight was taken from the rocks collected in the upstream and downstream areas because of the high number of dreissenids in these areas, whereas all individuals were enumerated for the central area. Number of individuals was divided by the total surface area of the collected rocks to provide an estimate of dreissenid density in each area.

Results

Within sites sampled from the central area, 20-minute angling trials yielded a mean catch of 11.3±1.6 (SE) gobies, significantly higher than in upstream (5.5±1.2 SE) and downstream (3.9±1.9 SE) sites (H=12.4, P=0.0021). Paired comparisons indicate that goby CPUE in central area sites was significantly higher than in upstream or downstream sites ($P<0.016$ in both cases).

Gut fullness was affected by location (area) and sampling period (two-way ANOVA, $P<0.001$ in both cases), whereas there was no significant location by sampling period interaction (P=0.07). Mean gut fullness across sampling periods was significantly higher in gobies from the upstream area than in those from the central area (Tukey HSD, $P<0.001$), whereas the difference between gobies occupying the downstream and central areas was not significant (P=0.56). Round goby gut fullness showed similar temporal patterns at the upstream and downstream areas, with the highest gut fullness in late July and the lowest in early August (Fig. 2). This pattern differed qualitatively from that of gobies occupying the central area, where a progressive decline in gut fullness began in July. Upstream gobies had a higher mean gut

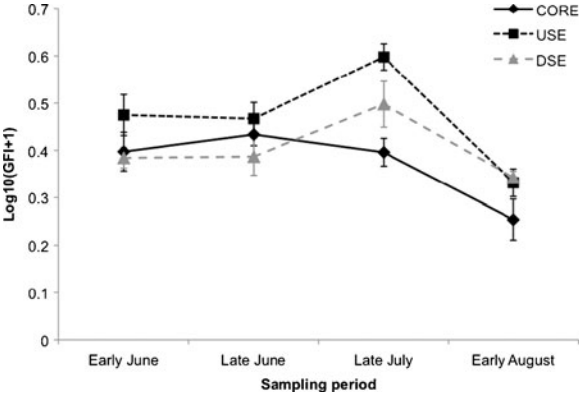

Fig. 2 Log-transformed gut fullness index (GFI) values for early June (June 10–11), late June (June 23–24), late July (July 21–24), and early August (August 6–7) in round gobies sampled from each of the three study areas (abbreviations as in Fig. 1). *Vertical bars* represent standard error of samples taken in the same area and sample period (total $n=169$)

fullness than those from the central area on all sampling dates, whereas gut fullness in the downstream area was comparable to that of the central area in June, and higher in July and August.

In examining round goby diet composition, it was evident that the proportion of dreissenid mass in the diet increased and the proportion of chironomids in the diet decreased with increasing fish size (Fig. 3). We therefore divided the gobies into two size classes (< 70 mm; ≥ 70 mm TL, following Barton et al. 2005) for subsequent site comparisons. Dreissenid consumption by the larger round gobies differed significantly among the three sites ($H=14.1$; $P=0.001$), and consumption of dreissenids as a percentage of fish weight was significantly lower in gobies sampled from the central area than those sampled from the upstream or downstream areas ($P<0.02$ in both cases; Fig. 4). In contrast, dreissenid consumption was not significantly different among the three areas for the smaller gobies ($H=1.61$, $P=0.45$). Post-hoc dreissenid sampling in April 2009 showed that mean densities of this prey type were considerably higher in the upstream and downstream areas (1184/m^2, 1657/m^2, respectively) than in the central area (131/m^2).

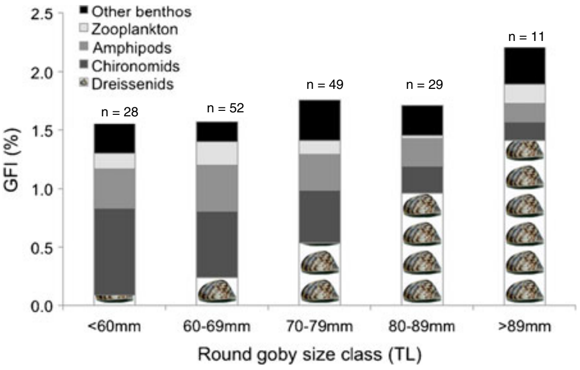

Fig. 3 Round goby gut fullness and diet composition (other benthos, zooplankton, amphipods, chironomids, and dreissenids) as an absolute proportion of gut fullness index (GFI) for each of five size classes ($n=169$). Zebra mussel image credit: USGS

Mean amphipod consumption relative to fish weight was lowest, on average, in gobies sampled from the central area, and this was the case in both large and small gobies. However, these differences were not statistically significant in either size-class ($H<4.27$, $P>0.10$ in both cases). Although chironomids were a more substantial component of the diet of large gobies sampled from the central area than those in the upstream and downstream

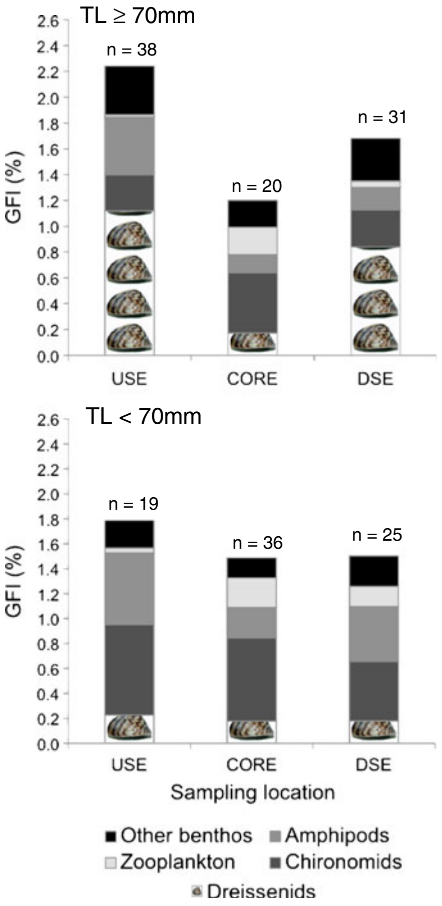

Fig. 4 Diet composition of small (<70 mm TL) and large (≥70 mm TL) round gobies in the three Trent River study areas (abbreviations as in Fig. 1)

areas, there were no significant differences among areas in chironomid consumption in either goby size-class (Fig. 4; $H<4.26$; $P>0.12$ in both cases).

Condition factor was significantly affected by location (sampling area) but not sampling period (two-way ANOVA, $P=0.002$, and $P=0.26$, respectively); however there was a significant location by sampling period interaction ($P<0.001$). As was the case with gut fullness, mean K_n across sampling periods in gobies was higher in the upstream area (1.103±0.008 SE), than in the central or downstream areas (1.071±0.009 and 1.066±0.009, respectively).

Discussion

Our study demonstrates that the type and quantity of prey consumed by the invasive round goby can vary along its invasion pathway, and our prediction that round gobies occupying the central area near the original introduction would consume a lower quantity of prey than those occupying the edges of range expansion was mostly supported. In the central area where the period of colonization was longest and goby density was highest, gut fullness was significantly lower than for individuals at the upstream edge of their expanded range, and was also lower than for individuals in the downstream edge in mid to late summer. Our prediction that lower consumption of the major prey types favoured by gobies would occur in individuals occupying the central area was only partly supported, but only in relatively large gobies (>70 mm TL) and only in their consumption of dreissenids.

Two alternate hypothesis could explain the prey consumption differences found in our study: a) differences in gut fullness and diet composition reflect a temporal reduction of prey resources in the central area, particularly dreissenids, resulting from a sustained high consumption rate by gobies, or b) the central area is inherently different in habitat and prey availability, and therefore lower goby gut fullness and differences in diet composition relative to upstream and downstream areas are unrelated to density-mediated reduction of prey. A lack of prey availability and quantitative habitat data to match stomach content data prevents us from definitively explaining among-area differences in goby stomach contents. However, sample sites were selected to minimize variation in habitat type so that habitat-mediated prey variation was likely also minimized. Further, research elsewhere has shown clearly round gobies can dramatically impact prey populations over time after colonization of new sites (Djuricich and Janssen 2001; Barton et al. 2005; Krakowiak and Pennuto 2008; Lederer et al. 2008). Whereas other research has focused on sampling prey populations to demonstrate 'before-and-after' effects, our study is the first to our knowledge to illustrate round goby invasion dynamics along a linear system, and to use consumption rate and diet composition to do so.

While round gobies occupying the central area had significantly lower gut fullness than those living in the upstream edge throughout the sample period, differences with the downstream edge of expansion were not evident until mid-summer (mid-July and early August). It is not known why goby prey consumption would differ between upstream and downstream areas in mean stomach fullness but not in the temporal pattern of gut fullness nor in dreissenid consumption, but there is some evidence to suggest that it is related to the density of native competitors in these areas. Fish community data collected with the Rapid Visual Technique (described in Pratt and Fox 2001) involving >15 trials distributed in and around seining sites in each of the three sampling areas showed that northern logperch (*Percina caprodes*) were considerably more abundant at the downstream edge than in the upstream edge (unpublished data, G. Raby). Although northern logperch do not consume dreissenids, they do have a number of other prey items in common with the round goby, and thus could have affected the availability of non-dreissenid prey through competition (French and Jude 2001).

Observed differences in gut fullness among sample areas may have been affected by the types of prey consumed. Corresponding with the findings of research in other systems invaded by the round goby, dreissenids, chironomids, and amphipods were the prey types most heavily consumed by this species (Ghedotti et al. 1995; Ray and Corkum 1997; French and Jude 2001; Diggins et al. 2002; Barton et al. 2005), although dreissenids were less important to the round goby in the Hungarian portion of the Danube River where the mussels were not very abundant (see Borza et al. 2009). Two of these studies also demonstrated that dreissenids were a more important prey item for larger gobies, with substantial dreissenid consumption beginning at ~70 mm (Ray and Corkum 1997; Barton et al. 2005), as was the case in the Trent River (Fig. 3). This is in contrast with data reported on a non-native population in the Serbian portion of the Danube River, where molluscs (mainly dreissenids) have been identified as preferred prey across all goby size classes (Simonovic et al. 1998).

Diet composition was similar between the downstream and upstream areas, whereas consumption of dreissenids by round gobies occupying the central area was significantly lower. Because round gobies commonly use dreissenids as a major prey source, it is likely that individuals at a newly colonized site where a previously unexploited dreissenid population exists will have more dreissenid biomass available than individuals at a site colonized years ago by round gobies. However, it should be noted that the energy density of dreissenids is lower than that of many non-mollusc aquatic invertebrates (see Eggleton and Schramm 2004) and thus, higher stomach content volumes by consuming more dreissenids and less of other prey types may not necessarily provide more gross energy to a goby that does this.

Among-area differences in relative condition factor followed a similar pattern as gut fullness, with gobies from the upstream area having a higher K_n and those from the downstream and central areas. However, differences among these areas in K_n were not consistent across sampling periods. More importantly, length-weight body condition should be interpreted with caution, as they can be confounded by spawning activity, which was occurring during a large part of the sampling period.

As stated, our results suggest that lower consumption of dreissenids by round gobies in the central area may be due to the numerical decline of this prey type as a result of round goby predation. Post-hoc sampling in April 2009 showed that mean dreissenid densities in the and upstream and downstream limits were an order of magnitude higher than that of the central site. However, without pre-impact dreissenid data in the three study areas, the link between diet composition and prey density is only suggestive of a goby effect on dreissenids.

Barton et al. (2005) showed a similar prey response to the round goby invasion in Lake Erie: at sites with increasing round goby density over 2 years, the density of dreissenids, and also of amphipods, decreased dramatically. The implication of this study and our own is that the effects of round goby invasions are dynamic—as their expansion progresses, former edges of their expanding range will become more like sites where they are already well established in terms of goby prey consumption, diet composition, and effects on invertebrate prey. However, like other invasive species, round gobies have shown a tendency to build up their density at the early stages of invasion, and show major declines later in time (Bøhn et al. 2004; Simberloff and Gibbons 2004; Young et al. 2010). The effect of these changes on localized densities of their prey are therefore likely to be dampened, with densities recovering as the invasive predator declines and the cycle moving outward as the range expands.

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