Effect of Human Development on the Biodiversity of Benthic Macroinvertebrates in Douglas Lake, Michigan

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General Ecology (EEB 381)
June 13, 2019
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ABSTRACT

As human development increases on waterfronts, aquatic ecosystems are subject to habitat changes that may risk their health. Freshwater organisms are affected by these environmental variations, and studying the effects on indicator species reveals potential dangers of human development. Benthic macroinvertebrates are small organisms that live on the bottom of freshwater ecosystems, and are often used as indicator species for ecosystem health, because of their ability to reflect pollution levels and their various functional traits. We sampled areas of Douglas Lake with high, moderate, and low levels of human development and found a significant difference in macroinvertebrate community composition between the three sites. Species richness, abundance, and diversity were not statistically different, but observed trends in each metric could be connected to human impacts.

INTRODUCTION

As inland lakes become increasingly popular destinations for vacations and recreational activities, the amount of artificially-made beaches and the construction of lakeshore properties have been increasing (Nzeka, 2018; Wynder, 2018) . These anthropocentric changes have led to a decrease in aquatic habitat diversity and variations in the water quality (Christensen et al, 1996; Engel & Pederson, 1998). Aquatic habitat-building vegetation has been found to be significantly less prevalent on lakeshores with human development (Radomski & Goeman, 2001). This endangers aquatic organisms like benthic macroinvertebrates, that rely on aquatic vegetation for shelter and sustenance.

Benthic macroinvertebrates, hereafter referred to as “benthos”, are aquatic organisms that live on the bottom of lakes, streams, and rivers. Their low mobility that renders them unable to avoid pollutants, as well as their have significant roles in various ecosystem functions, makes them an invaluable tool for freshwater biomonitoring. Hakiki et al. (2017) used benthos to measure the effect of pollutants on stream quality in Indonesia. The streams were found to be affected by a variety of human activities like industry, ports, oil refineries, tourism, and cement production processing. In this study, benthos had a positive correlation with stream depth, salinity, pH, DO, and type of soil substrate. Diversity of benthos was lowest at the site located near a waste disposal plant. Benthos are sensitive to a range of pollutants and can be negatively affected when faced with environmental pressures (Friberg et al., 2010). Benthos are frequently used as indicators of pollution, environmental health, and water quality in aquatic systems. Macroinvertebrates are the most widely used organisms for monitoring human impact on freshwater systems (Bonada et al., 2005). They are a unique monitoring mechanism compared to other water quality measurements because they can be used to assess biotic ecological functions in response to changing abiotic factors (Bonada et al., 2005).

Benthos are vital for the health of these freshwater ecosystems. These organisms play a crucial role in the aquatic food web by serving as both predator and prey, contributing to the food chain from the bottom up and the top down. Certain benthos consume periphyton and algae, others eat plant or animal material, and some act as filters of water in their consumption of fine particulate matter (Wallace et al.,1996). They are also key actors in nutrient cycling, as they are responsible for the primary uptake and recycling of decaying organic nutrients produced by riparian vegetation detritus (Strumpf et al., 2009).

The effects of human development and pollution can have adverse effects on benthos, which are some of the most sensitive and foundational members of aquatic ecosystems. Schlacher and Thompson (2012) reported that a modified sediment matrix caused by increased recreational use of Australian beaches resulted in a significant decrease in abundance and diversity of benthos in that area. Patang et al. (2018) investigated the diversity of benthos in various Indonesian freshwater streams and determined that the decreased species diversity at one sampling location was due to increased human activity in that area.

The Douglas Lake Nature Preserve lies within a United Nations protected biosphere. It is made of many bays. Three of the largest bays in the area are Maple Bay, North Fishtail Bay, and South Fishtail Bay. North Fishtail Bay is mostly protected from shoreline development. However, Maple Bay is very developed and has many homes built along the shoreline. South Fishtail Bay, where the biostation is located, has moderate development. Based on previous studies that show the effects of human activity on aquatic ecosystems, we expect to see a difference in species composition among the different bays in Douglas Lake. Specifically, we hypothesize that a higher level of human development will have a negative impact on the benthos of Douglas

Lake, resulting in a lower species diversity along the populated beachfront areas. We also expect to see a negative relationship with the level of human development and species richness and individual abundance.

METHODS

Study Site

Our study took place in the Northern lower peninsula of Michigan (45.5770° N, 84.6929° W). We sampled from three bays in Douglas Lake, a kettle lake that emerged after the glaciers receded from Northern Michigan. Maple, South Fishtail and North Fishtail Bay, all have different levels of human development. These sites were selected using satellite imagery from Google Earth based on their differing levels of visible human development. Maple Bay is a highly developed area, with many docks and houses lining its shore. It is hereafter referred to as our “high development” study site. North Fishtail Bay has little to no development, there are no visible houses along its shoreline. It is hereafter referred to as our “low development” study site. South Fishtail Bay, our “moderate development” site, has intermediate human development, with the University of Michigan Biological Station the only development on it (Figure 1).

We sampled each site using three 30-meter transects and ensured that the depths were between two and five meters, to control for variations due to depth. We selected this depth for its accessibility, any deeper and we would have needed to change our sampling method, and to ensure that the species we found at the sites could be found at any site with the same depth.

Data Collected

We created a sample-based species accumulation curve to determine the number of samples we needed to take to get an accurate representation of all present species (Figure 2). Along a 30-meter line, in sample area separate from our study sites, we used a D-Net to perform four 1-meter long collections along the lake bottom, hitting the net on the sediment three times before pulling up the sample. We then transferred each sample to a bucket. The buckets were processed using a metal sieve and water to flush out sediment. We transferred the macroinvertebrates to a sectioned ice cube tray using forceps and each species was identified by comparison to a dichotomous key and placed in their own individual section. The number of each species was recorded. After all samples were collected and identified, organisms were put back into the lake. From the species accumulation curve, we determined that twelve samples needed to be taken from each site.

In each of our study sites, we marked off a 30-meter by 30-meter area, marking three transects parallel to the shore at 10, 20 and 30 meters. Using a D-Net, we performed four 1-meter-long collections along each transect (Figure 3). We repeated the collection process for the remaining eight scoops along the other two transects, putting each scoop from one transect into one bucket. The buckets were processed as described above and the individuals were recorded. Before collecting D-net samples, we collected water samples from the middle of our 20-meter transect using acid-washed

Nalgene bottles. We took the samples from the bottom of the lake because that is where the benthic organisms live.

Data Analysis

We used R statistical software to run an ANOVA to compare species richness across each site. To compare community composition between the levels of development, we ran a Chi-square test for all 16 species. To further measure zebra mussels we ran a separate ANOVA and compared average abundance across each site. To compare diversity we ran an ANOVA test of average Shannon-Weiner Diversity indices of each site. In comparing abundance of total average number of individuals at each site, we ran an ANOVA.

RESULTS

Macroinvertebrate Community Composition

Across all three sampling locations, a total of 16 benthic macroinvertebrate species were found (Table 1). On average, each of the study sites had a significantly different composition of macroinvertebrate species, showing that human development has an effect on the species composition of an aquatic ecosystem. Community composition differed significantly in all three comparisons: high to low development, low to moderate development, and high to moderate development (X^2=77.48, df=12, p<0.0001; X^2 =43.78,1 df=13, p<0.00; X^2=64.427, df=11, p<0.0001, respectively; Figure 4).

Species Abundance

Our results suggest no relationship between species abundance and human development; and ANOVA comparing mean species abundance between the sites indicated no significant difference between any of the sites: high to low development, low to moderate development, and high to moderate development ($F= 1.409$; $df = 2$; $p=.31$, $p=.51$, $p=.90$, respectively; Figure 5). Looking at zebra mussels specifically, an ANOVA indicated that there was no significance in average abundance of mussels in across the three sites: high to low development, low to moderate development, and high to moderate development ($F= 1.065$; $df = 2$; $p=.42$, $p=.53$, $p=.97$, respectively; Figure 6).

Species Richness

Our results suggest no relationship between species richness and human development; an ANOVA comparing mean species richness between the sites indicated no significant difference between all three sites: high to low development, low to moderate development, and high to moderate development ($p=0.405$, $p=0.405$, $p= 1.000$, respectively; Figure 7).

Species Diversity

The ANOVA done for the Shannon-Wiener Diversity Index compared the average diversity indices across the three sites, showing no difference in the average species diversity among high, moderate, and low levels of development. This suggests that human development does not affect biodiversity ($F= 1.314$, $df = 2$, $p=0.34$; Figure 8).

Water Quality

Water tests from each sample site showed differences in the amounts of nitrogen, phosphorus, and chlorophyll-a. Water from the high development area contained 2.783 μg/L of chlorophyll-a, 500 μg/L of nitrogen, and 10 μg/L of phosphorus. Water from the low development area contained 2.258 μg/L of chlorophyll-a, 400 μg/L of nitrogen, and 5 μg/L of phosphorus. Water from the moderately developed area contained 1.299 μg/L of chlorophyll-a, 300 μg/L of nitrogen, and 7 μg/L of phosphorus (Table 2).

DISCUSSION

Abundance

Different species had varying levels of abundance within the three bays, and species composition was statistically different. While their difference in abundance was not statistically different, caddisfly larvae were highest in number in the high development bay and lower in both the low and moderate development bays. In choosing a habitat, caddisfly larvae select for depth (Teague et al., 1985), which may explain their abundance at the high development site, the deepest of the three sample sites.

Statistically, there was no difference in zebra mussels within all three bays. In our samples, zebra mussels were the most abundant in the high and moderate development bays. Zebra mussels are introduced to lakes from boat bilges and attaching to trailers and the outsides of boats. They prefer litoral zones of lakes and are limited to a 1-6m depth (Karatayev et al., 2014). The most boat traffic on Douglas Lake is in the high development bay where the boat ramp is located. Zebra mussels are introduced to lakes by attaching to outside of boats, trailers, and residing in bilge water. Boat traffic is also high in the moderate bay from the University of Michigan Biological Station, where research boats are kept and used daily. In the low development bay there are no docks or boats kept. Strayer et al. (1999) found that human activities correlate to a large increase of zebra mussel populations which lead to severe decline in native species. We suspect that the frequency of human activity in the areas of high and moderate development is likely related to the abundance of zebra mussels there, and potentially the lower abundance of other species. The effect of less boat frequency and a quantification of hard substrate for zebra mussels to attach to could be a focus for future research explaining varied zebra mussel abundance between the bays.

Richness

There was a lower number of species in the study site with a low level of development. Our samples from that area also reported the lowest number of individual organisms, and the decrease in species richness may be correlated with the decrease in individual abundance. The decrease in richness could be explained by ecosystem pressures, such as competition. In areas of low development, selective processes that would control for population size are likely unrelated to human disturbance. Intraspecific and interspecific competition may be the dominant forces at work in low populated areas, since the macroinvertebrate habitat is not being actively disturbed by human activity, and resource abundance is neither increased nor decreased. Thus, a lesser amount of total individual species would be able to coexist in non-disturbed areas due to the disproportionately large effect of competition for resources (Mayfield et al., 2010).

Differences in species richness may have also been impacted by water quality and presence of nutrients. Water quality tests conducted at the three sites all showed different levels of nitrogen and phosphorus present, with the high development site having the highest chlorophyll-a, nitrogen, and phosphorus levels overall. Since the presence of chlorophyll-a indicates the occurrence of photosynthesis, and photosynthesis is a key component of productivity, then the presence of chlorophyll-a can be used as a metric for productivity. Thus, the high development area was the most productive bay according to chlorophyll-a content.

Diversity

Species diversity, as determined by a Shannon-Weiner diversity test, was not different across the three sites. The SWI in the low development area was the lowest of the three sites, and could be a result of biotic functional homogenization. As described by Olden et al. (2004), this phenomenon is characterized by a lower species diversity, reflective of the lower composition of various functional traits required by the ecosystem. With little environmental variation in a habitat, species that exhibit redundant ecosystem services will be subject to competition that forces them out of that particular niche. A classification of benthos according to their biological traits by Usseglio-Polatera et al. (2000) determined that caddisflies typically functionally overlap with organisms in the orders Diptera, like dragonfly nymphs, and Gasteropoda, like orb snails. Lower numbers of caddisflies and snails were reported in the low development study site compared to the other two areas, perhaps suggesting that a functional niche was preferentially filled by dragonfly nymphs in that location. Areas with a lower amount of human development face less anthropogenic habitat variation, and there are less functional niches to fill.

While potentially less diverse, homogeneous habitats may not be dysfunctional, but perhaps more efficient in providing certain ecosystem services catered to their specific ecological constraints. Changes in ecological habitats of any magnitude, including but not limited to human development, could risk the health of any ecosystem. Olden et al. (2004) explain that biotic homogeneity makes ecosystems more vulnerable to environmental variation. While our low development study site may be functioning properly for its environmental conditions, any disturbance could drastically harm the ecosystem. A further direction for study could investigate discrete consequences of increased human-caused disturbance over time, to determine more clearly the relationship between biotic homogeneity, ecosystem function, and human development.

GRAPHS AND STATISTICS

Figure 1. Map of study sites; a) low developed area (North Fishtail Bay), b) moderately developed site (South Fishtail Bay), and c) highly developed area (Maple Bay).

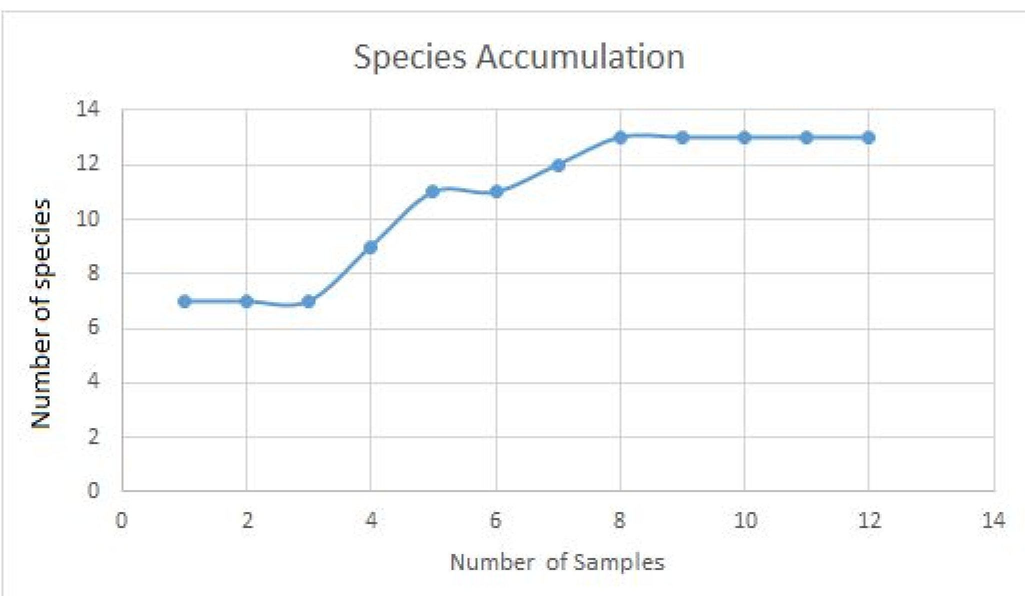

Figure 2. Species accumulation curve: the cumulative number of species found with each sample determined that 12 samples was sufficient to represent the total number of species in the sample area.

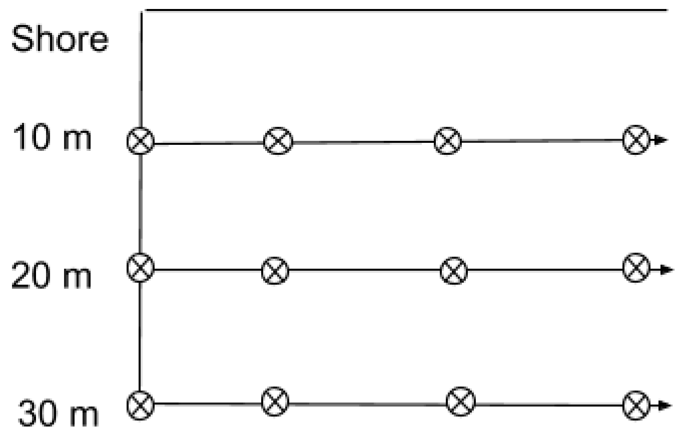

Figure 3. Depiction of sampling method at study sites.

Table 1. Description of species composition at each site

Species	Maple Bay	North Fishtail Bay	South Fishtail Bay
Amphipod	64	7	21
Caddisfly Larvae	74	19	28
Damselfly Larvae	0	0	4
Dragonfly Larvae/Nymph	15	27	35
Gilled Snail	10	4	12
Horsehair Worm	0	1	0
Mayfly Larvae	12	1	17
Midge Larvae	1	2	3
Orb Snail	3	0	12
Pill Clam	62	48	64
Pouch Snail	7	1	0
Riffle Beetle Larvae	0	0	0
Segmented Worm	4	0	1
Threadworm	0	1	0
Zebra Mussel	147	26	127

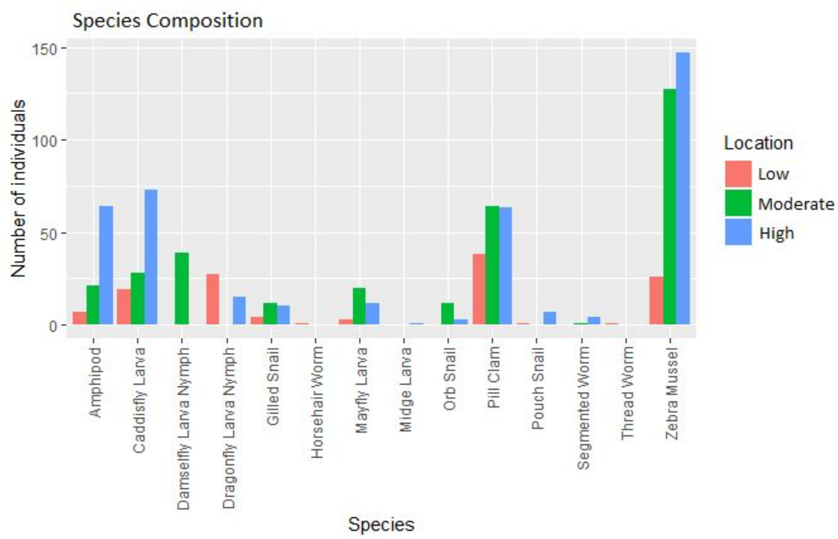

Figure 4. Species composition: the number of each species found at each location. There was a significantly different distribution of species across the locations.

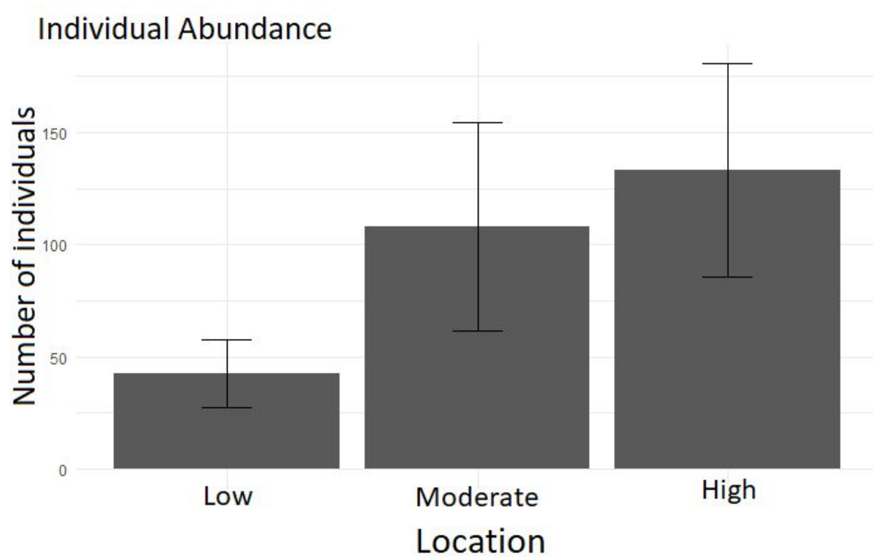

Figure 5. Individual Abundance: there was no significant difference between the number of individuals found at each location. There is no relationship between the level of development and individual abundance.

Figure 6. Number of Zebra Mussels per Location: mean number of zebra mussels found per transect at each location. There is no significant relationship between the level of human development and zebra mussel abundance.

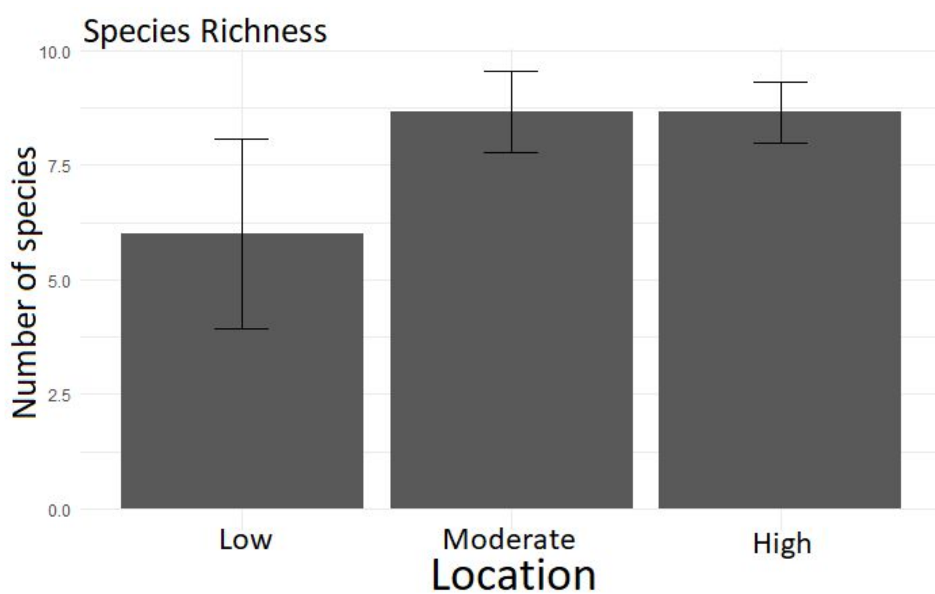

Figure 7. Species Richness: mean number of species found per transect per location, representative of the richness of each transect at each location. There was no significant difference in the number of species found at each location; there is no relationship between species richness and level of development.

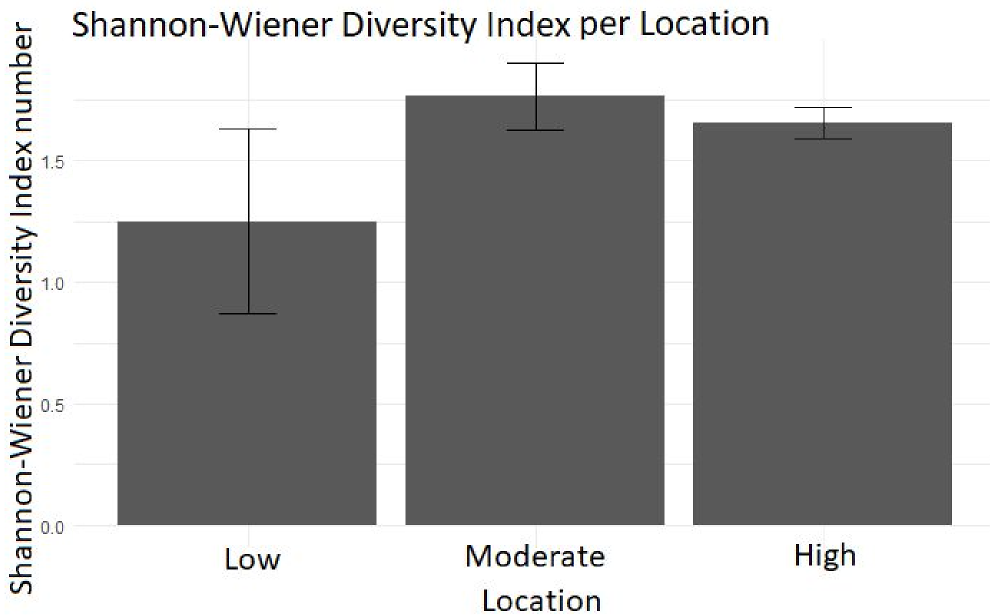

Figure 8. Shannon-Wiener Diversity Indices: mean Shannon-Wiener-Index for each location. The differences between mean Shannon-Wiener-Index between the three sites was not statistically significant. There is no relationship between species diversity and level of human development.

Table 2. Chlorophyll-a and nutrient abundance found in one water sample from the middle transect at each location.

X (ug/L-1)	Chl-a	Total N	Total P
Blank	0	<10	<1
Low Development	2.258	400	5
Moderate Development	1.299	300	7
High Development	2.783	500	10

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