Computer simulations of two catching algorithms to improve the efficiency of catching fish

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Abstract

We try to understand the efficiency of two proposed algorithms to catch fish, and use regression analysis, to differentiate between the two models, in this paper. This study was motivated by an ever increasing demand of fish for a rising population in the UK. The output of this industry to the UK economy is substantial to encourage future research into the topic. We use regression analysis to account for standard errors in the data points obtained and calculate the errors in the intercepts for all cases. We find that the food source algorithm (a model which uses major food sources in an arbitrary lake as checkpoints for a gathering of a school of fish) is a more realistic model for catching fish. We observe that the speed of the boat explains $\approx 68\%$ of the variations in time taken to catch the fish and that the area of the lake explains $\approx 50\%$ of the variations in time taken to catch the fish. We also propose further study into this topic will aid the UK economy and provide a sustainable food source for future generations.

1 Introduction

Early humans i.e. Neanderthals have had a long history of catching fish as a sustainable food source dating back to 200,000 BC. Modern humans have been fishing since 100,000 BC [Carr, 2017]. It is speculated that this association with fishing over the millennia led to some important inventions and techniques to catch fish mainly the invention of fishing boats and nets. The oldest canoes used for fishing were invented more than 7500 years ago but with the advent of the Industrial Revolution, the process has now been mechanised. The modern fishing trawler was developed in Brixham in the 19^{th} century [Marchaj, 2007]. The advent of the railways during the 1830s also led to an increase in the demand for fish from the population inland in the UK and trawling became more widespread [Knauss, 2005]. The development of steam trawlers in the 1880s thus marked the start of a rapid expansion of the fishing industry that continued until the late twentieth century in the UK [Robinson, 1996].Steam power enabled vessels to fish further offshore, for a longer duration, with larger gear, which could reach deeper[Robinson, 1996][Trawl Net and Beam Trawl Fishing, 1885]. Fishing is still a massive industry today, contributing £980 million to the economy in exports [Elliot and Holden, 2017]. The UK fishing industry comprised of 4000 jobs and contributed £1.4 billion to the UK economy in terms of Gross Value Added [Ares, Rhodes and Ward, 2017]. Thus it is clear that it is still extremely relevant to fishermen on how to catch fish efficiently, to increase profits. The rising world population is also a major incentive for this study, it is expected to grow from the present 7.3 billion people to about 9.7 billion by 2050 [UN-DESA, 2015]. This paper tries to create and analyse realistic computer simulations to test two algorithms to catch fish faster and more efficiently and to try to show the better one of the two, through the use of statistical analysis and a realistic approach. The aim of the paper is to show how the area of a lake, the speed of a school of fish and the speed of the boat, changes how fast and efficiently the fish can be captured. The two methods both revolve around understanding how fish behave. Our first preliminary model focuses solely on how fish move and if the position is known, how fast can the fish be caught. As, primarily, food dictates how fish move, we have simulated four main food sources in an arbitrary lake of area A, with a school of fish modelled as a point particle with speed v, and the speed of the boat b, and we try to find out how these parameters affect how long it takes the boat to catch the school of fish.

2 Methodology

The three main factors which influence the motion of fish are

- Environmental parameters: A secondary use of these simulations may also be habitat assessment, stream restoration, and management and conservation of fish populations [Santillana et al., 2013]. It has been observed that estuaries are composed of natural rich-structured habitats such as mangrove forests, beaches and marshes, and that they serve as potential fish nursery areas by provisioning shelter against predators [Beck et al., 2001]. But such habitats are difficult to construct in simulations due to the variety of characteristics of such habitats such as spacial and temperate conditions. Thus such parameters were also not considered in the formation of the algorithms stated below.

- Abundance of food sources: Other secondary factors may be the size and number of shared prey, and diet breadth [Lucas, 2000]. Dietary overlaps among fish species is also a valid parameter, but due to simplicity of calculations and the analysis of simulations, the fish in consideration can be thought of being a single species.

- Shelter: In water bodies with man-made structures, increased fish richness and diversity is related to the increased availability of animals living on the seafloor, rather than using separate shelters [Wheeler, 1980]. Thus this parameter is considered to be relatively unimportant in the context of this paper, as a lake is more than likely to have man-made structures, such as jetties. As the computer simulations are 2D it is impossible to ascertain how deep the fish are in relation to the boat, so is not considered.

The motion of waves in 2D simulations is an exciting parameter to consider to see whether it influences the motion of fish, but recent studies show that there is no influence of water flow regime on school swimming behaviour [Nadler et al., 2018] i.e. the waves created in lakes would not theoretically have an impact on the motion of the school of fish.

The first method taken into consideration is the preliminary method, where we assume that the boat and the fish start at random points in the lake each time. We assume that the boat travels in a straight line. We assume that the fish travel in straight lines with turns in random directions. This assumption is backed by the fact that study into effects of fluid dynamics using virtual fish moving in two dimensions, has shown that the fish show four distinct modes of collective motion, one of which is 'aligned swimming with frequent spontaneous turns' [Filella et al., 2018]. We assume that that the boat and the school of fish can be treated as point particles. This is mainly to simplify the modelling but also as theoretical models often assume that each fish follows some simple 'local' rules, such as aligning themselves with the average orientation of those nearby [Couzin et al., 2002]. This effects cohesion within the school of fish and allows it to be modelled as a particle. We then assume that the position of the fish is known to the boat. The DIDSON is a multibeam sonar that uses an acoustic lens to form the individual beams [Belcher, Hanot and Burch, 2002]. The DIDSON has been established as an instrument platform for observing and enumerating the passage of fish in water bodies [Handegard and Williams, 2008]. At the moment, the methods used to determine the movement of fish include video software analysis, marker positioning based on radio and acoustics, accelerator trajectory analysis, or manual counting [Castro-Santos and Haro, 2010] [Watanabe et al., 2012]. Thus, it is clear that there is technology in place to locate fish using certain techniques. So the assumption that the fish can be tracked whilst moving randomly, can be considered to be valid. The units of length and time are pixels and seconds respectively. The aim of this model is to collect and plot data with the area of the lake, the speed of the boat and the fish being independent variables and the time taken to catch them being the dependent variable. A calculated line of regression will show the best fit of the data points, and the units can be then changed into metres per second and compared to real world values of speeds of boats and the school of fish.

The second method taken into consideration in this paper is the modelling of food sources in the lake as potential headings of a school of fish. We assume at each iteration of the simulation that the boat and the fish start at random points in the lake. As it has been well established that birds in a flock find food faster and more efficiently [Krebs et al., 1972], we can assume that a school of fish also have such an advantage [Curio, 1976]. We infer that the school of fish, modelled as a point particle, then head straight towards the nearest of the food sources. Among the first mathematical results concerning fish-like swimming linearly through simulations were those reported by Lighthill [Lighthill, 1960]. Yet it has also been observed that state-of-the-art technologies cannot keep correct identities for long term when tracking many objects [Xu and Cheng, 2017]. So the fish swimming linearly can be taken to be a good modelling technique in the problem and the assumption that the boat cannot see the fish can be considered to be equally valid as compared to the approach used in the first model. We also assume that the initial and any subsequent trajectories the fish might take are completely unknown to the boat. This makes the simulation more realistic. The boat starts at an arbitrary food source and loops through the four food sources until the school of fish and the boat reach the same food source i.e. they collide. Similar units of length and time are used.

Both the models mentioned above use programs written in Python using the graphics module, to simulate the fish tracking. The use of Python was to maintain focus on the main functionality of the simulation by taking care of the easier tasks and breaks a requirement into smaller pieces, which are then easily executed. The simple syntax in Python helps keep the code readable.

There are many studies which can determine the biomass in a lake [Selin and Hakkari, 1982] [Samarasin et al., 2015] [Trifonova, 2015] but none that can generalise these results to any lake with area A. This is due to various other parameters such as the differences intensity of sunlight for various geographical locations, and the seasonal temperature variations during the year. Thus, to focus primarily on the area of the lake, the speeds of the boat and the fish and how they affect the time taken to catch the fish, the above parameters and thus the total biomass in the lake will be kept constant. We assume that there are a constant number of major food sources in any lake at any given time. This is backed by the fact that ecological differences between species are not enough to outweigh the effect of seasonal variations in resource abundance [Heng et al., 2018]. So, our assumptions can be generalised for any species of fish without affecting the results of the simulations drastically.

We will expect certain logical trends in the data such as there being a positive linear relation in the increase in area of the lake and the time taken to catch the fish, as there will be a bigger lake for the fish to evade capture. There will also be a negative linear relation between the speed of the boat and the time taken to catch the fish, as a faster boat will catch the fish faster. The graphics module works so that the highest value of the speed gives the slower speed for the particle. We expect there to be a negative linear relation as the true equation will be a reflection in y = x.

3 Pseudo-code for the algorithms

The first model's program differs through the lack of use of food sources and will setup turtles for the boat and the fish. When the program starts, a timer starts as well. If the fish and the boat collide then the terminal prints "fish caught", the timer ends and prints the time elapsed.

```
initialise the index_counter to zero

while index_counter <= 10
    set width and height of the lake
    set a delay time variable for 100
    setup window where the simulation will take place

    setup the boat as a particle
    set the boat speed

    setup the school of fish as a particle
    set the speed of the fish

    // the centre of the simulation window contains the centre of the coordinate axes
    used in this program
    set x_coords and y_coords to be half the size of the width and height of the lake

    // this program written in python used random.randint to generate random integers
    within a given range.
    // find random positions for the fish and the boat.
    set positions of the boat and the fish randomly using random integers in the range
    between the x_coords and y_coords

    setup the positions of the boat and the fish

    define distance_between_points(distance between x_coords, distance between y_coords)
        return square root(distance between x_coords^2 + distance between y_coords^2)

    define collision_between_points(distance between x_coords, distance between y_coords)
        return absolute value(distance between x_coords < 1 and distance between y_coords < 1)

    define end_timer
        set begin_time to when the simulation starts
        set end_time to when the simulation ends
        elapsed_time = end_time - begin_time

    // fish's motion is random
    define random_motion_of_fish
        set fish speed
        call function boat_to_fish
```

```
        initialise counter to zero
        while counter <= 20000:
            set fish heading using random integers in the range of 0 to 360
            set fish trajectory by setting random integers as trajectory
            lengths from -50 to 50 pixels
            set fish speed
        counter = counter + 1

    define boat_to_fish
        set heading of the boat towards the position of the fish
        set boat trajectory
        if collision_between_points(boat, fish)
            print "fish caught"
            call function end_timer
            set delay of the fish and the boat using the delay variable
            initialised at the start

    call function random_motion_of_fish
    call function boat_to_fish

index_counter = index_counter + 1
```

The second model's program differs through the use of food sources and will setup turtles for the boat, the fish and four food sources. When the program starts, a timer starts as well. If the fish and the boat collide then the terminal prints ”fish caught”, the timer ends and prints the time elapsed.

```
initialise the index_counter to zero

while index_counter <= 10
    set width and height of the lake
    set a delay time variable for 100
    setup window where the simulation will take place

    setup the boat as a particle
    set the boat speed

    setup the school of fish as a particle
    set the speed of the fish

    setup four food sources for the fish
    set the dimensions of the food sources

    // the centre of the simulation window contains the centre of the coordinate axes
    used in this program
    set x_coords and y_coords to be half the size of the width and height of the lake

    // this program written in python used random.randint to generate random integers
    within a given range
    set positions of the boat and the fish randomly using random integers in the range
    between the x_coords and y_coords
```

```
    setup the positions of the boat, the fish, and the four food sources

    define distance_between_points(distance between x_coords, distance between y_coords)
        return square root(distance between x_coords^2 + distance between y_coords^2)

    define collision_between_points(distance between x_coords, distance between y_coords)
        return absolute value(distance between x_coords < 1 and distance between y_coords < 1)

    define check_shortest_path_from_fish_to_food(positions of food sources)
        if distance_between_points is the least for fish to food for any food source
            setheading of the fish to that particular food source

    define end_timer
        set begin_time to when the simulation starts
        set end_time to when the simulation ends
        elapsed_time = end_time - begin_time

    define straight_motion_of_fish
        set fish to move forward at the speed given above
        call the function check_shortest_path_from_fish_to_food(food1, food2, food3, food4)
        call the function check_shortest_path_from_fish_to_food(food2, food1, food3, food4)
        call the function check_shortest_path_from_fish_to_food(food3, food1, food2, food4)
        call the function check_shortest_path_from_fish_to_food(food4, food1, food2, food3)
        set delay of the fish and the boat using the delay variable
        initialised at the start

    define motion_of_boat
    // loop through the positions of the food sources until collision
        for token_food = 1
            setheading of boat towards token_food
            if collision_between_points(fish, boat)
                print "fish caught"
                print "The time elapsed is", elapsed_time
        token_food = token_food + 1


    // access the simulation window and call the functions
    set begin_time
    call function straight_motion_of_fish
    call function motion_of_boat

index_counter = index_counter + 1
```

4 Results

Generally we observe that the results follow the predicted logical trends. Further regression analysis is given below.

- The first algorithm:
  For the data set for the area of the lake plotted against the fish capture time, the line of

regression has the equation

$$y = 3 \times 10^{-5}x + 12.303 \tag{1}$$

The standard error in the results is 6.631. The y-intercept of the graph is 12.303. The expected value of the y-intercept is zero (and all y-intercepts for positive linear relations), but this value can be explained by the fact that the delay in the simulations (see the delay variable mentioned in the pseudo-code) was not considered in the calculations. The standard error in the calculation of the y-intercept is 2.256. The R squared value is 0.586 which indicates that the area of the lake explains nearly a 59% of the variation in time taken to catch the fish.

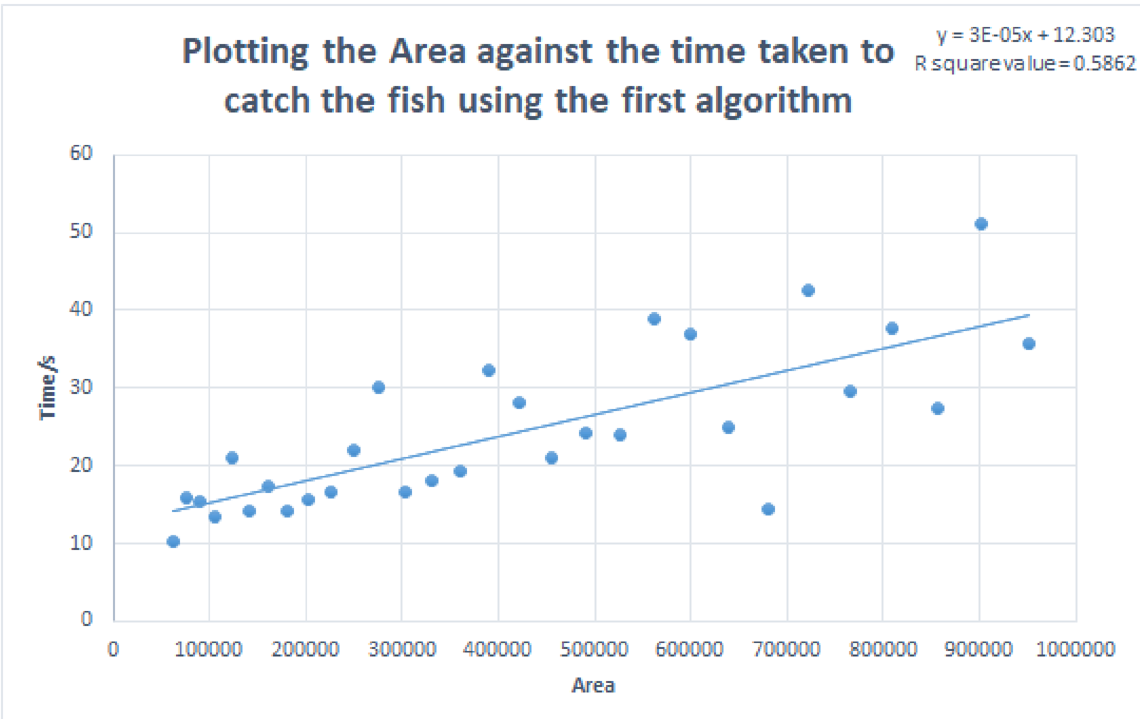

Figure 1: *The area of the lake plotted against the time taken to catch the fish as seen using the first algorithm and keeping the values for the speeds of the boat and the fish constant*

For the data set for the speed of the boat plotted against the fish capture time, the line of regression has the equation

$$y = 5.630x + 56.085 \tag{2}$$

The standard error in the results is 12.348. The y-intercept of the graph is 56.085. The standard error in the calculation of the y-intercept is 6.768. The R squared value is 0.510 which indicates that the speed of the boat explains 51% of the variation in time taken to catch the fish.

For the data set for the speed of the fish plotted against the fish capture time, the line of regression has the equation

$$y = -8.059x + 56.467 \tag{3}$$

But this equation needs to be reflected in y = x for reasons mentioned in the methodology.

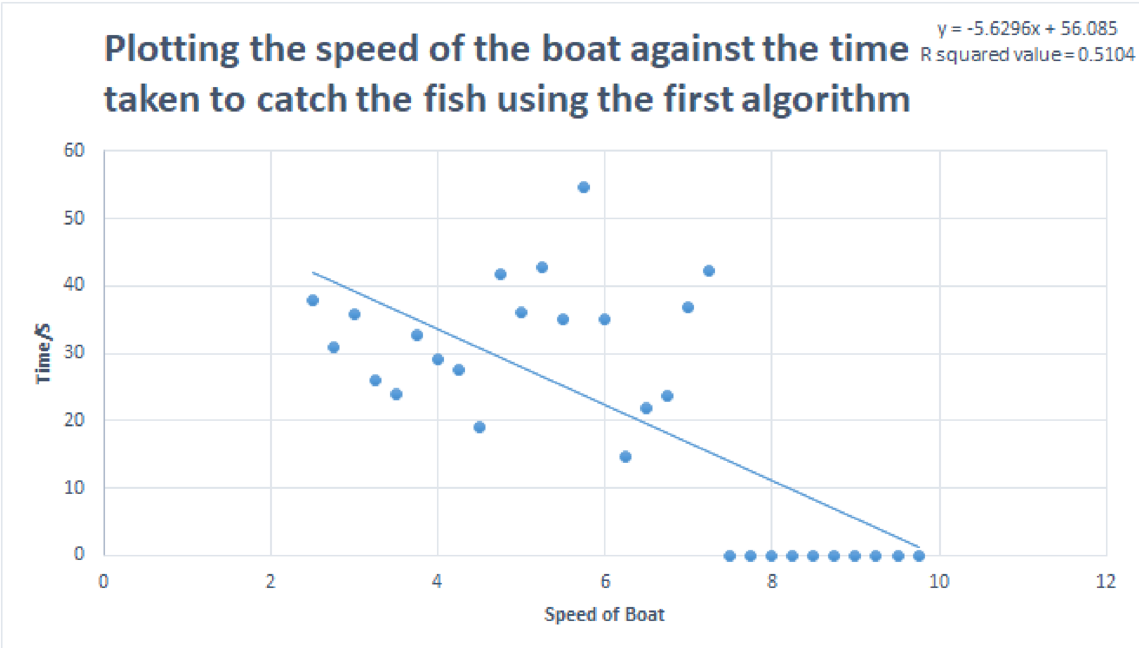

Figure 2: *The speed of the boat plotted against the time taken to catch the fish as seen using the first algorithm and keeping the values for the area of the lake and the speed of the fish constant*

Thus the true equation is

$$y = -0.124x + 7.006 \tag{4}$$

The standard error in the results is 1.120. The y-intercept of the graph is 6.411. The standard error in the calculation of the y-intercept is 6.768. The R squared value is 0.750 which indicates that the speed of the fish explains 75% of the variation in time taken to catch the fish.

- The second algorithm:
  For the data set for the area of the lake plotted against the fish capture time, the line of regression has the equation

$$y = 5 \times 10^{-5}x + 19.046 \tag{5}$$

The standard error in the results is 12.943. The y-intercept of the graph is 19.046. The expected value of the y-intercept is zero (and all y-intercepts for positive linear relations), but this value can be explained by the fact that the delay in the simulations (see the delay variable mentioned in the pseudo-code) was not considered in the calculations. The standard error in the calculation of the y-intercept is 4.404. The R squared value is 0.497 which indicates that the area of the lake explains nearly a 50% of the variation in time taken to catch the fish.

For the data set for the speed of the boat plotted against the fish capture time, the line of regression has the equation

$$y = -4.5203x + 43.171 \tag{6}$$

The standard error in the results is 6.998. The y-intercept of the graph is 43.171. The standard error in the calculation of the y-intercept is 3.836. The R squared value is 0.677 which indicates that the speed of the boat explains $\approx 68\%$ of the variation in time taken to catch the fish.

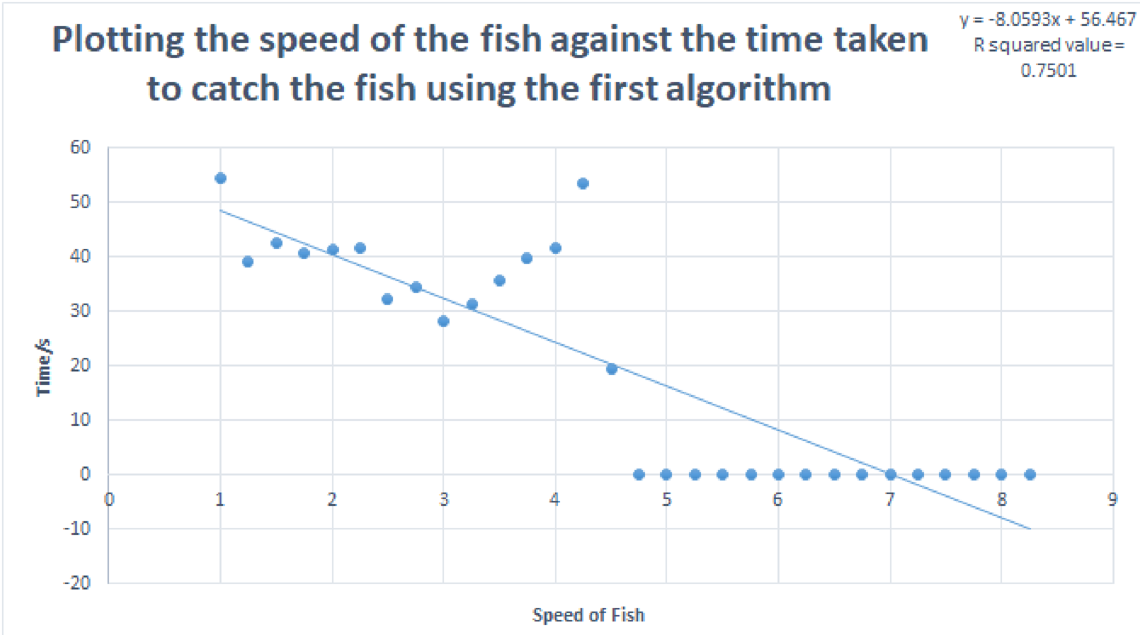

Figure 3: *The speed of the fish plotted against the time taken to catch the fish as seen using the first algorithm and keeping the values for the area of the lake and the speed of the boat constant*

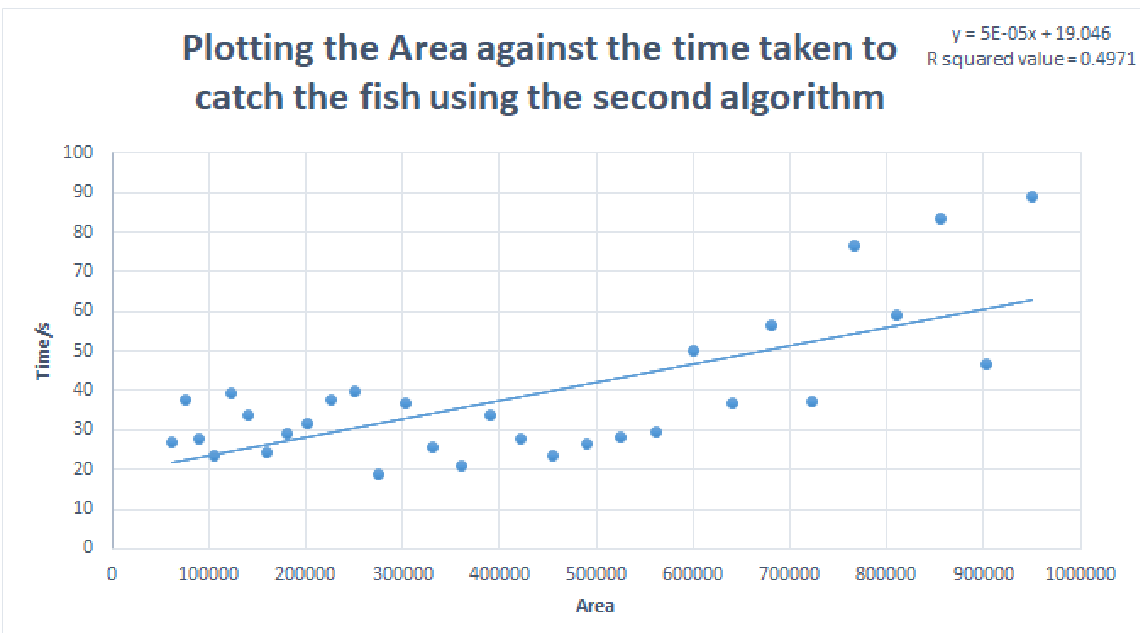

Figure 4: *The area of the lake plotted against the time taken to catch the fish as seen using the first algorithm and keeping the values for the speeds of the boat and the fish constant*

For the data set for the speed of the fish plotted against the fish capture time, the line

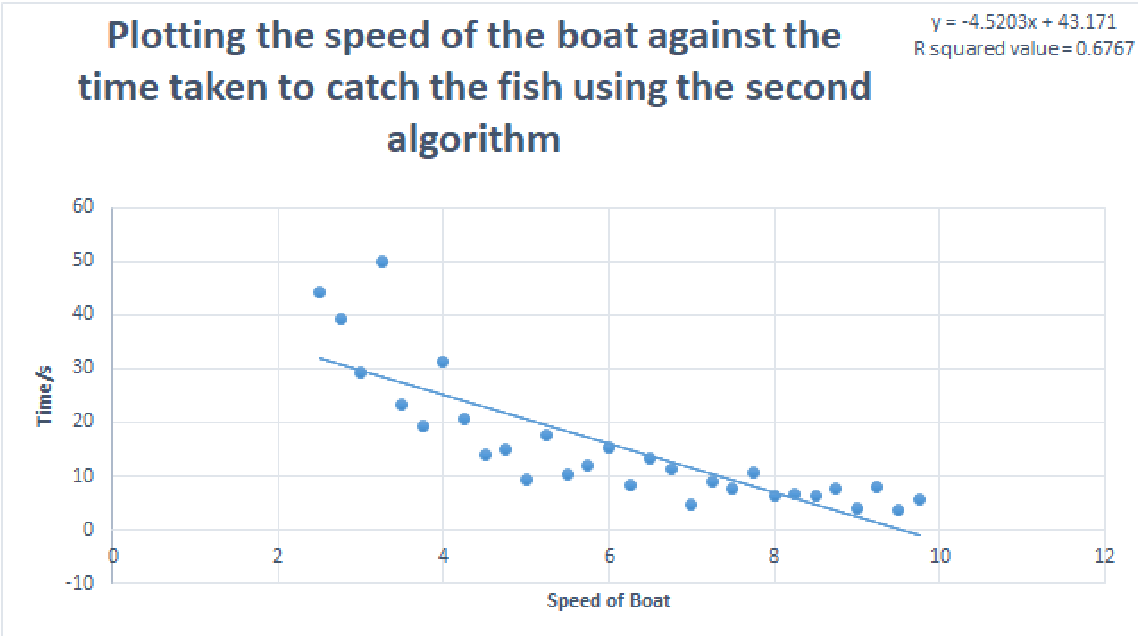

Figure 5: *The speed of the boat plotted against the time taken to catch the fish as seen using the first algorithm and keeping the values for the area of the lake and the speed of the fish constant*

of regression has the equation

$$y = -2.061x + 87.376 \tag{7}$$

But this equation needs to be reflected in y = x for reasons mentioned in the methodology. Thus the true equation is

$$y = -0.485x + 42.391 \tag{8}$$

The standard error in the results is 2.222. The y-intercept of the graph is 42.391. The standard error in the calculation of the y-intercept is 6.768. The R squared value is 0.016 which indicates that the speed of the fish explains $\approx 2\%$ of the variation in time taken to catch the fish.

5 Discussion

Through careful analysis of the results, we observe that with an increase in the fish and boat speeds, it is more and more difficult to collect data (see Figure 2 and Figure 3) where the data points lie on the x-axis; indicates that it takes too long for the simulation to occur and so the data points were not considered). A limitation of the model is that we assume the boat and the fish to have constant velocity and thus no acceleration. This reduces the realism of both models. Another limitation of this experiment is thus the oversight of considering these points as potential outliers, but they have been kept in to show the general trend of the data, and to pick up flaws in the original design of the program. Yet, the first algorithm consistently gives a higher value for R squared, which indicates a better fit for the data points. The standard errors in the results are evenly distributed with 12.348 and 12.943, the largest errors for the boat-time plot for the first algorithm and the area-time plot for the second algorithm respectively. The second algorithm, in retrospect, has an abnormally low value for the R squared value for the speed of the fish plotted against the fish capture time (see Figure 6). Thus, the first algorithm is statistically a better fit for the data points, but taking a

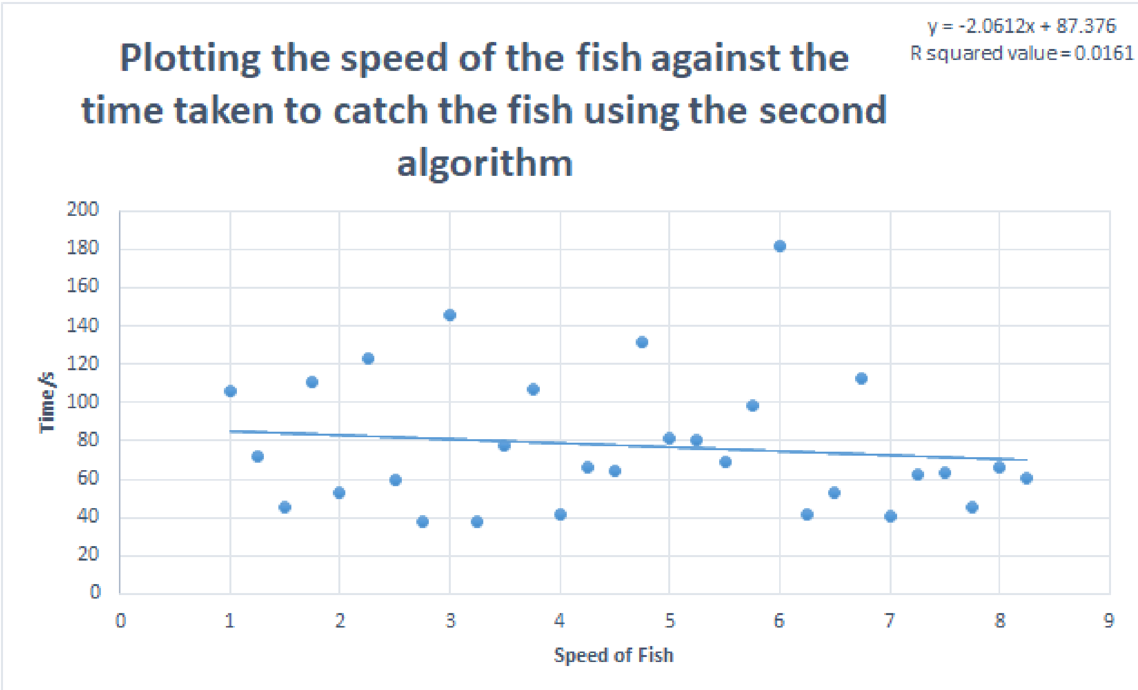

Figure 6: *The speed of the fish plotted against the time taken to catch the fish as seen using the first algorithm and keeping the values for the area of the lake and the speed of the boat constant*

more realistic approach, the second model corresponds the closest to how fishermen used to hunt for fish without the use of technology. There is a dearth of information on how fishermen track fish, as most sources suggest a knowledge of the sea and educated guesses tend to help fishermen and our analysis suggests a need to explicitly consider the role of environmental parameters and how different amounts and sizes of food sources can affect the fish capture time. Using Typography and Digital Imaging Units, we can convert from pixels to metres (1 metre = 3779.52755905511 pixels) and the equations stated above can be used to extrapolate for different lake sizes, and speeds of fish and boats. As the technology to track fish in real time is still not readily available, the second algorithm is the better one of the two to catch fish efficiently.

6 Conclusion

The statistical analysis leads us to believe that the first model is better than the food source model, but it relies on live tracking of the fish. This technology is not as refined today, but it is a good preliminary model, as it shows the expected trends of the data points. The food source model depends on the fish going to the closest food sources, which is realistic, but it also depends on the boat knowing the positions of all major sources in the lake, which is unlikely. This model has the advantage of being backed by the extensive literature review which agrees that food, along with environmental parameters and shelter is of primary concern to the survival of fish, and that food sources are the easiest to model. In general,when the area of lake gets larger,the collisions will occur less frequently. We assumed that the speed of boat is higher than that of the fish at the beginning. However, when we observed the simulations, the boat still caught the fish even with lower speeds. In addition to improving the code to eliminate the bias, when the sample is large enough, recording unsuccessful data can be used to find a probability distribution function which will facilitate the statistical analysis for the study.

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