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A SYSTEM DYNAMIC MODEL FOR A SUSTAINABLE SQUID POPULATION IN PERAK, MALAYSIA

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Abstract— *Loligo Duvauceli*, is known as squid in the local name. Squid is a species of high value and a good source of protein besides fish. This paper presents a model of dynamic squid behaviour and a system dynamic model. The purpose of the model is to develop a sustainable model for squid population, growth and harvesting. This model is carried out through several basic tests to determine its sensitivity to changes in crucial parameter and initial value with different value and boundary conditions. The model result shows that growth, biological catch and harvesting must be adjusted quickly in response to changing conditions to improve fishery sustainability.

Keyword— System Dynamic, sustainable, squid, population, parameter, growth, biological catch, harvesting

1 INTRODUCTION

System Dynamics (SD) rooted in the invention of industrial dynamics by Forrester in the 1950s to analyze complex behaviors in social sciences through computer simulations [1]. As one of the main methods in the system thinking approach, SD has evolved and termed as an interdisciplinary approach. The definition needed to be established due to a situation where decisions can solve a problem resulted in unpredictable outcomes [2]. In practice, SD is a powerful dynamic simulation modelling tool that can mimic behavior characteristics of a real complex problem and incorporate the feedback processes within [3]. SD is also focused on nonlinear dynamics and feedback control theory, which can be used in mathematics, physics, and engineering [2,4,5]. These compelling traits make SD an effective approach for the policy design process[3].

The word “system”, as defined by [6], is a collection of parts that act together and function as a whole. Therefore, the system will always be more significant than its part. Furthermore, the word “dynamic” in SD indicates the continuous change of state over time or corresponds to the system's changes. Thus, SD can be defined as the combination of system components to solve equations in a dynamic environment and

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correspond to the system's changes [4 7].

The International System Dynamics Society describes SD as "a computer-aided approach to policy analysis and design.” It refers to dynamic problems that occur in complex social, managerial, economic, or ecological systems–in other words, any dynamic system characterized by interdependence, reciprocal exchange, information feedback, and circular causality.”

This paper shows how to use system dynamic modelling techniques to construct a sustainable squid population growth model (Vensim. Inc., 2012). With the increase of the global population, continued squid overfishing, and waste of natural resources, the long-term survival of the squid population has put a risk. There are several warnings these days of squid populations decreasing in ponds, rivers, and seas. By using a dynamic model, we try to maintain a sustainable squid population. SD a practical approach for the policy design process.

2 LITERATURE REVIEW AND THEORETICAL

The system dynamics methodology has addressed challenges in many disciplines, including policy research and architecture, environmental studies, healthcare, manufacturing, and more. This section summaries previous literature, which is broken down into several areas of application.

Fields	Authors	Application
economics	[8]	To provide a timeline for the state of Sarawak government in managing the transition from s production-based economy to a knowledge-based economy.
	[9]	project in a rural region of mid-eastern China is used as the study case to simulate the practical process inspired
	[10]	Sustainable Development of Tasik Kenyir Eco-Tourism
Business Management	[11] - [13]	To simulate a business process

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	[14]	To investigate business cost factors
	[15] – [16]	To analyse supply chain management
	[17] – [18]	To address the managerial and organisational problems of Turkish insurance company
	[19]	To assess the most successful scenario for ensuring end-user loyalty in the consumer goods delivery chain,
Insurance	[20]	This analysis aims to see how deposit insurance benefits influence critical stakeholders in a commercial bank.
	[21]	To model, identify, and help manage human development and economic growth in Pakistan.
	[22] – [23]	To solve problem in the area of disease epidemiology, particularly HIV/AIDS
	[24] – [25]	To determine the unintended consequences of healthcare service expansion.
Health	[26] – [27]	To identify the most effective behavioural change strategy from dietary intake and physical activity improvement to prevent obesity.
	[28]	To model healthcare integration in three different institutions.
	[29]	To model emergency department operations from a whole system perspective.
	[30]	To assess the imbalance that exists between the limited university capacities and huge demand for higher education in Turkey.
Education	[31]	To assist the National Ministry Education in the schooling system in Nicaragua. The model shows that without a change in the education policies, the number of illiterate people will be doubled in the future.

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	[32]	The causal study of the framework structure of high-quality education information resource allocation, defining the relationship between the flow diagram and equation of high-quality education information resource allocation system, mining the determining factors of high-quality education information sharing rate and evaluating the influence of various factors on the sharing rate of high-quality education information.
	[33]	The article adds to the debate on countries' knowledge-based growth by reflecting on Ghana and using a framework complex approach to explore the existence and implications of interactions between academia (university) and business (market), addressing causality, partnerships, and addictions.
	[34]	to build appropriate modelling models for analysing the complicated and dynamic relationships between student flows, personnel ratios, and plant and facility investments
	[35]	The interactions of automatic system components and the long-term behaviour of irrigation networks were investigated using a dynamic system approach.
Agriculture	[36]	to focus on how much farm land is available to cover complex shifts in the climate
	[37]	To offer an interconnected and systematic model for examining the current trends in Iran's farming industry's sustainable growth.

Fisheries is an essential field in terms of environmental protection. Over the last three decades, understanding sustainability among government, business, and the general public has increased significantly [38]. Globally, policymakers have tried to integrate environmental factors into urban and industrial growth [39]. Sustainability in the fisheries sector could be accomplished by improved planning of fish harvesting and stocks.

We need to explore the possibilities of how we can use these resources prudently

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without reaching limits that impose burdens on the ability of the World. Economist Herman Daly has proposed three introductory rules to help identify the sustainable limits of material and energy efficiency [40]:

1. For renewable materials,' the sustainable rate of use should not be greater than the regeneration rate.'
2. The sustainable usage rate for non-renewable resources cannot be greater than the rate of substitution of a renewable resource.
3. The sustainable emission rate for contaminants cannot be greater than the rate at which the pollutant in its sink can be recycled, absorbed, or made harmless.

Without a sustainable substitution insight, it is difficult to sustain any activity that causes a stock of renewable resources to decline, emissions sink to rise, and non-renewable resources to fall [40]. This is also true for fisheries since they make use of natural resources.

Squid is one of the living cephalopods that comes from the ancient group of Molluscs [41]. According to [42], the scientific name for squid is *Loligo Duvauceli*. It is also known as "*Sotong"* in the local name. The other species include nautiluses, bottles squids and bobtail, pygmy cuttlefishes, cuttlefishes and octopus. Squid also have a shell, but it is buried in their flesh, also known as the pen, that consists of a strip of cartilage. There are approximately 700 species of cephalopods have been identified in the world [41].

According to Roper [43], the ocean holds approximately about 500 species of squids. Cephalopods species are commonly found in the South China Sea and other adjacent sea areas, including the Northern end of the South China Sea for South Asian countries [41]. However, the South China Sea has a lower diversity of cephalopods than in the Japanese seawater.

Squid hatching occurred between February and August. The peak in the austral winter/spring and another smaller peak in the austral summer have been counted their age using the statolith micro increments and back-calculation from their captured data [44]. Male squid that was hatched in the winter/spring or summer showed different growth rate. In the winter/spring-hatched individuals, their growth rate was more variable, and they are getting more extensive than summer hatched. Mean mantle length or body mass does not show any significant difference, but their mean age for immaturity is significantly higher in the winter/spring. No squid was found to be older than 211 days. They started to mature by 91-120 days old and fully mature at 180 days.

The fisherman worldwide harvest squid by trawling, seining, trap fishing, pot fishing, gill net fishing and jigging [45]. Except for trawls, all the other gears are usually operated at night time using artificial light on-board of the fishing boat.

Squid harvesting plays an essential role in the fishing industry because of its demand in the market. Market squid is an important species to the coastal pelagic species fishery. The market squid resource is a monitored species, which means their landings and available abundance indices are considered sufficient to manage the stock. About 7.5% of the total catches by trawlers in the Gulf of Suez are dominated by cephalopods, by

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which 5% are cuttlefish, and 2.5% are squids [46].
The major fish group in the Malaysian fisheries, which account for five to six per cent of the total fish landings, goes to cephalopods [47]. The information on their biology, distributions and migrations activities is very scarce compared to the finishes. The dominant squid species in Malaysian water are *Loligo Duvaucelli, Loligo Chinensis* and *Loligo singleness*. The squids in the West Coast of Peninsular Malaysia areas are more abundant than the East Coast of Peninsular Malaysia. *Loligo Duvaucelli* is the squid species that dominate the catch on West Coast. Squids are mobile and active species that are highly migratory during their lifespan. The time and the period of study are closely related to their distribution, abundance and spawning activities.
We conclude that progress towards sustainability could be made by implementing complex approaches to the system. In this post, we are trying to use system dynamics modelling to grow the squid population. The system dynamics model 48] may be used in fisheries to monitor the growth of the fish population, fish stocks and harvest.

3 MATERIAL AND METHODS

3.1 Study Area

According to records, Perak has the most extensive number of licenced fishing gears compared to other locations on the West Coast, with a total of 3,797. According to the data, there are 1,380 for trawls nets, 1,524 for drift/gill nets, 536 for another seine, and the rest for other gears. Squid catch by trawls net is the highest in the record based on the Landing of marine fish by gear group and species compared to other gear [49].
The data of squid for this research is obtained from the Department of Fisheries. The details in graph 1 portray squid landings in Perak from 1998 to 2011.

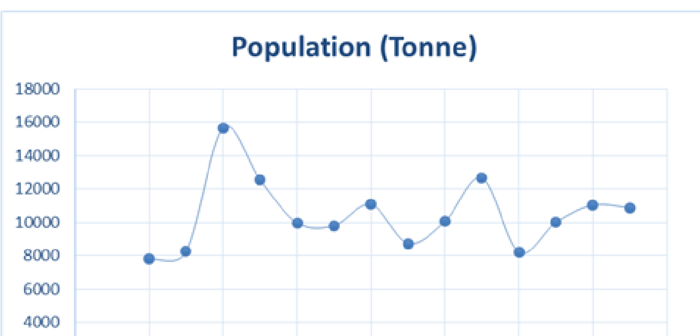

Figure 7: the landing Squid in Perak for the year 1998-2011

The logistic growth model is used to study the population of squid. The finite difference

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method is used to solve the nonlinear equation for the growth rate (r) and carrying capacity (k). Equation (1) shows the value of parameter growth rate, r=0.7706 and carrying capacity, k=12716. The equation is autonomous, and it is possible to solve directly for equilibrium and bifurcation values.

3.2 Squid Population Dynamics

The complex biomass (Gordon–Schaefer) concept is used to model the squid population. The increase in young fishes due to reproduction is equal to the squid growth rate multiplied by the current population, less the usual decline in squid multiplied by the ratio of matured squid to the squid stock holding power. The logistic growth model can be written as [50]:

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{k}\right)$$
(1)

Here the variable P can be interpreted as the size of the population. Its development over time, *P(t)*, depends on its initial value, P(0). On the two parameters r and K, where r is called the rate of squid survive at the maturity stage and K is referred to as the population's carrying capacity. Time is measured in months. There will be an initial population number, and it reaches the carrying capacity of a certain number within a total simulation time of a certain number of months.

In the system dynamics format, the model is shown in Figure 2. There is a disparity in theory between the original formulation and the approach to system dynamics. System dynamics models press for progress over time, and system dynamics modellers usually try to imagine each part of the model separately and explain the component-link structure.

3.3 System Dynamics Model

System dynamics is about a computer simulation technique that utilises a feedback approach in analysing behaviour over time of a complex and dynamic system. A computer simulation model is developed to assist management in making effective decisions.

System dynamics provides an approach for designing policies for the better behaviour of large dynamic systems. Many system dynamics models are concerned with the relationship between humans and their environments. *System dynamic* is an approach

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that focuses on describing and designing policies to represent how a system currently works [51]. SD is a simulation model that deals with complex, non-linear, deterministic, and closed boundary structures [52]. For the time being, [6] describe SD as a fundamental from feedback control theory, which encompasses both soft (qualitative) and hard (quantitative) approaches to evaluating development's complex behaviour.

System dynamics is a method of defining the modelled system as a series of simultaneous ordinary differential equations and then numerically combining those equations to approximate the system behaviour. We simplify assumptions based on the constraints set out in the fish population growth scenarios to construct a dynamic system model.

In SD models, diagrammatic distinctions (stocks, flows, auxiliaries, parameters, and constants) are made between different variable types. Stocks are an integral flow equation. Flows and auxiliaries are equations of specific variables and parameters/constants and assume (constant values over a simulation period. For SD models, the correlation between variables and parameters is only a direct causal relationship. Model structure, historical data fit, and model behaviour comprise a wide range of tests [53]. The model structure verification and reliability were verified by stakeholder discussion and a literature study.

The system dynamic modelling and sensitivity analysis were conducted using the software Vensim PLE 7.2.

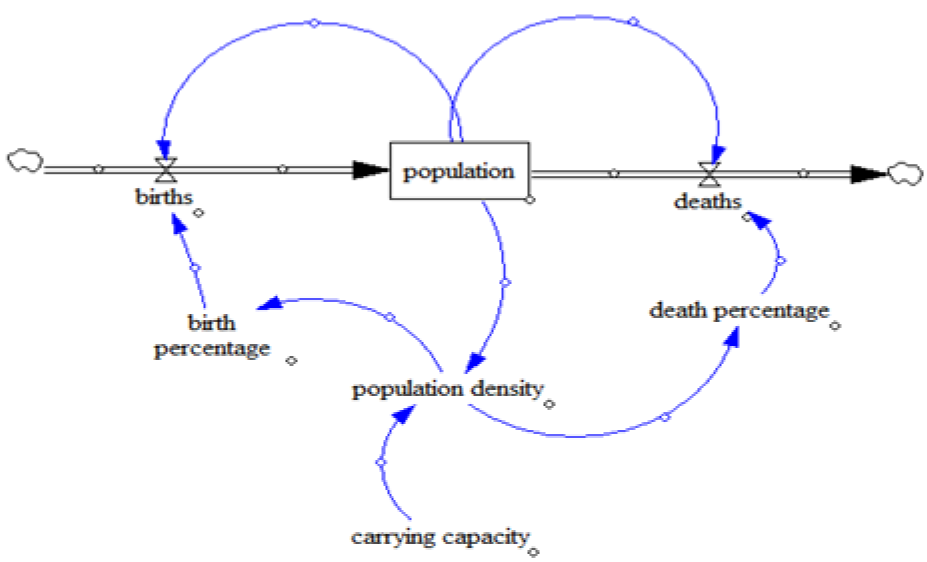

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Figure 1: A Forrester's diagram representing the element of the model together with their relationship.

4 RESULT AND DISCUSSION

Population growth should be stable, which is near the carrying capacity. However, if the population significantly approaches the carrying capacity, the population can rapidly achieve equilibrium. When the flows into storages balance the flows out of storages, the storages' prices do not change in a dynamic equilibrium. A feedback loop is introduced in the model.

From the model in Figure 1, we have come up with some equations to test for assumptions. The equation of population density-dependent on birth percentage is [54]:

Birth percentage = 0.15/population density

(2)

The equation is working well with an initial population *of 100* and a carrying capacity *of 1300*. The sensitivity of the model by change the initial population to 4000 and keeping carrying capacity as *1300*, we found the birth rate for the month one was calculated as low as 3% still it should never fall below 10%. The equation work well with *N=100* and *K=1300* and with *N=4000* and *K=1300* as well.

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Time (Month	"birth	birth percentage	"death	death percentag	"population"	population
0	percentage"	1.5	percentage"	0.01	Runs:	100
1	Runs:	0.60241	Runs:	0.0249	Current	249
2	Current	0.381874	Current	0.03928		392.8
3		0.28443		0.0527371		527.371
4		0.230926		0.0649559		649.559
5		0.198055		0.0757366		757.366
6		0.176469		0.0850006		850.006
7		0.161681		0.0927755		927.755
8		0.151258		0.0991682		991.682
9		0.143769		0.104334		1043.34
10		0.138315		0.108448		1084.48
11		0.134304		0.111687		1116.87
12		0.131333		0.114213		1142.13
13		0.129123		0.116169		1161.69
14		0.127471		0.117673		1176.73
15		0.126235		0.118826		1188.26
16		0.125306		0.119707		1197.07
17		0.124609		0.120377		1203.77
18		0.124083		0.120886		1208.86
19		0.123688		0.121273		1212.73
20		0.12339		0.121566		1215.66
21		0.123165		0.121788		1217.88
22		0.122996		0.121955		1219.55
23		0.122868		0.122082		1220.82
24		0.122772		0.122178		1221.78
25		0.122699		0.122251		1222.51
26		0.122644		0.122305		1223.05
27		0.122602		0.122347		1223.47
28		0.122571		0.122378		1223.78
29		0.122547		0.122402		1224.02

Figure 2: The birth rate and death rate of squid with *N=100* and *K=1300*

Time (Month	"birth	birth percentage	"death	death percentag	"population"	population
0	percentage"	0.0375	percentage"	0.4	Runs:	4000
1	Runs:	0.0588235	Runs:	0.255	Current	2550
2	Current	0.0731797	Current	0.204975		2049.75
3		0.0842885		0.17796		1779.6
4		0.093		0.16129		1612.9
5		0.0998165		0.150276		1502.76
6		0.105121		0.142693		1426.93
7		0.109225		0.137332		1373.32
8		0.112383		0.133472		1334.72
9		0.114804		0.130657		1306.57
10		0.116654		0.128586		1285.86
11		0.118062		0.127051		1270.51
12		0.119133		0.125909		1259.09
13		0.119946		0.125056		1250.56
14		0.120562		0.124417		1244.17
15		0.121029		0.123938		1239.38
16		0.121382		0.123577		1235.77
17		0.121649		0.123306		1233.06
18		0.121851		0.123101		1231.01
19		0.122003		0.122947		1229.47
20		0.122119		0.122831		1228.31

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Figure 3: The birth rate and death rate of squid with *N=4000* and *K=1300*

Figure 4 shows that the birth rate and death rate change as expected and the population growth also stable as expected.

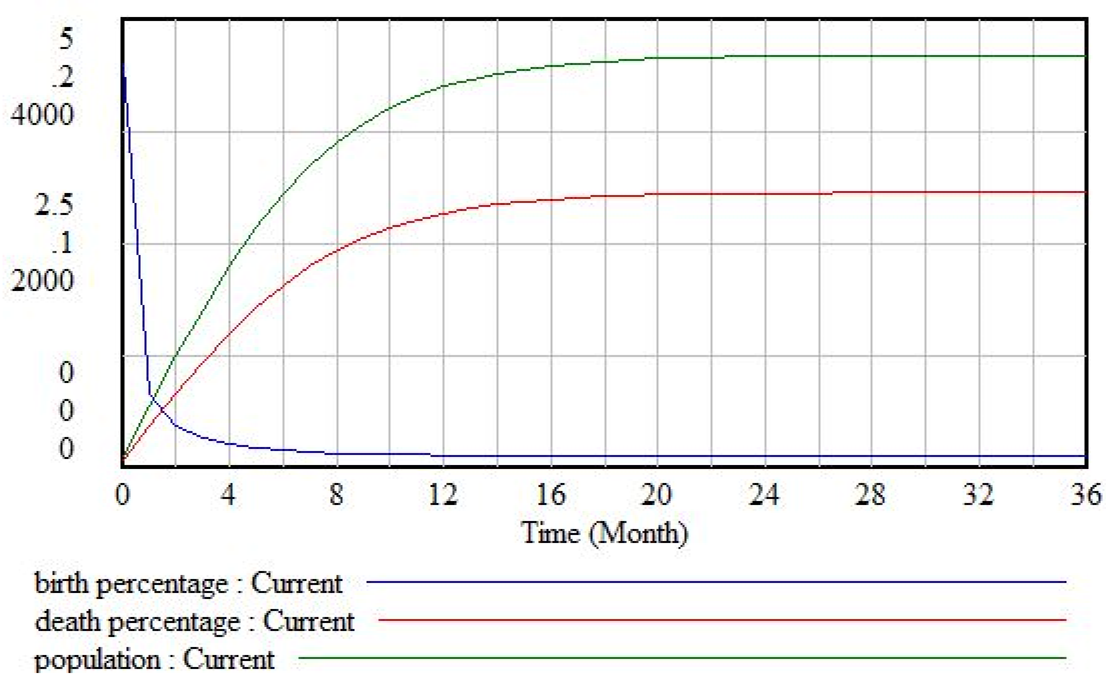

Figure 4: The graph of birth rate and death rate of squid with *N=100* and *K=1300*

Besides that, the model has a birth and death rate problem when the population exceeds carrying capacity from Figure 3, when the *N=4000*, we can see that the birth rate is down to 0.03, although it should never be less than 1.0. It is how to check their sensitivity analysis. In this model, the equation for birth rate did not work as expected. We expect that if the population density falls to zero, the maximum birth rate must stay 50%, and when population density stays 1.0, the minimum birth rate stays 10% [54]. According to [54], they added a parameter "population density max", which reset population density to 1 if it goes above 1 to make sure that the birth rate does not fall to 10%.

Population density max = IF THEN ELSE (population density >= 1, 1, population density) (3)

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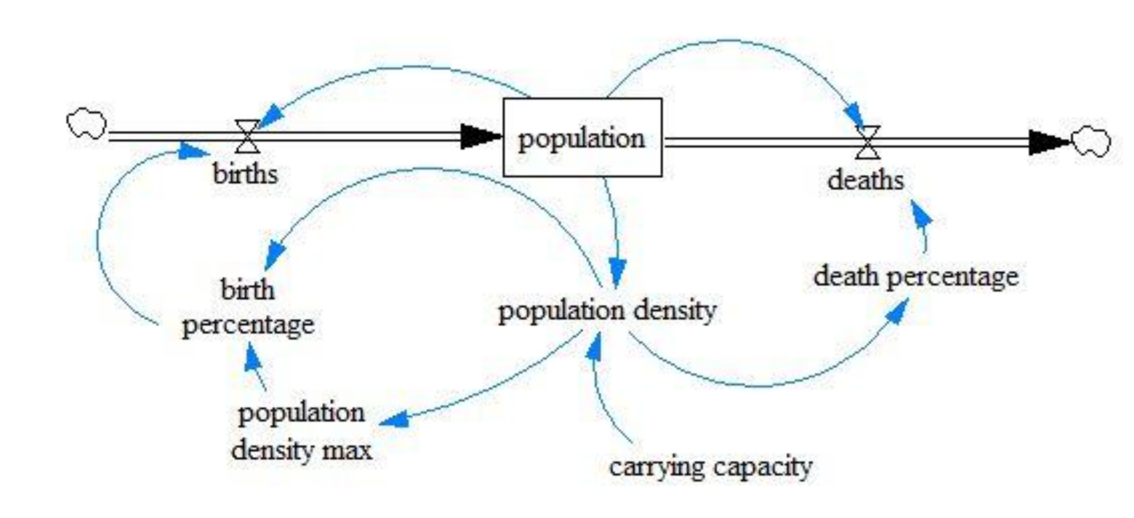

Figure 5: Final population growth

Time (Month	"birth	birth percentage	"death	death percentag	"population"	population
0	percentage"	0.5	percentage"	0.107692	Runs:	100
1	Runs:	0.49684	Runs:	0.11071	Current	139.231
2	Current	0.485001	Current	0.113371		173.817
3		0.474631		0.115701		204.111
4		0.4656		0.11773		230.495
5		0.457773		0.119489		253.359
6		0.451021		0.121007		273.085
7		0.445217		0.122311		290.04
8		0.440245		0.123428		304.565
9		0.435998		0.124383		316.973
10		0.432378		0.125196		327.547
11		0.4293		0.125888		336.54
12		0.426687		0.126475		344.173
13		0.424472		0.126973		350.644
14		0.422597		0.127394		356.122
15		0.421011		0.12775		360.754
16		0.419671		0.128051		364.668
17		0.418541		0.128305		367.971
18		0.417586		0.12852		370.759
19		0.416782		0.128701		373.109
20		0.416104		0.128853		375.089

Figure 6: The birth rate and death rate of squid with *N=100* and *K=1300* with final population growth model

The range of birth rate is 50% to 10%. From Figure 6, we can see that when the population is near to carrying capacity, the birth rate is 10%, and when the population is thin, the birth rate is 50%.

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To check the sensitivity analysis of birth rate calculation with any initial population and carrying capacity, we turn off the death rate equation before running the simulation. Then, sensitivity analysis of the death rate is checked. The result is well. We expected the population growth to fall immediately in Figure 5.

The graph in Figure 8 shows the result with initial population 100 and carrying capacity 1300.

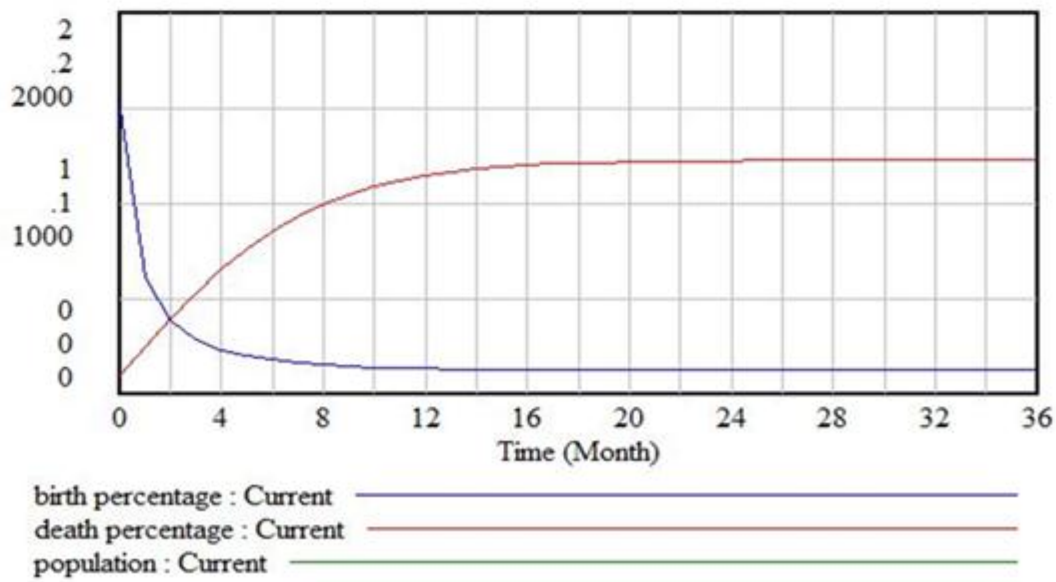

Figure 8: Based on starting point information given

Figure 6 shows that the birth rate and death rate with N=100 and K=1300 with the new equation population growth model work well. Figure 4 and Figure 8 were compared. The equilibrium in Figure 4 was achieved a bit late with the same initial population but with a carrying capacity of 1300.

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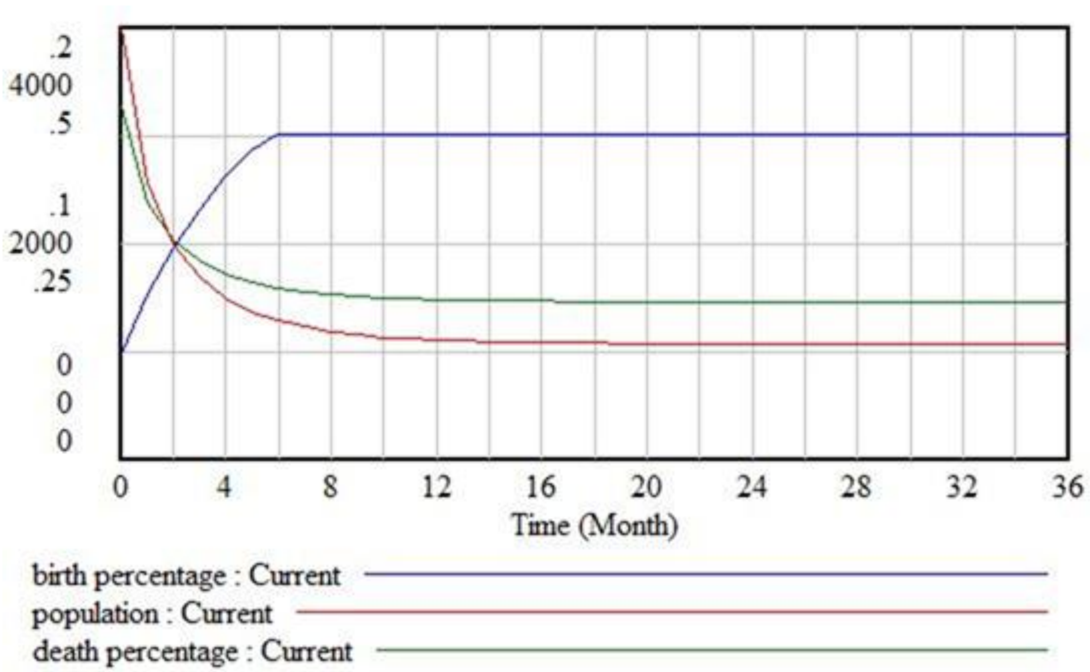

Figure 9: The graph of birth rate and death rate with N=4000 and K=1300

The graph in Figure 9 shows the result with an initial value greater than carrying capacity (1300). The table in Figure 10 also shows that the new equation for birth fraction works well with N is changed to 4000 and K=1300. The population comes down to near carrying capacity very fast and equilibrium achieved.

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Time (Month	"birth percentage" Runs: Current	birth percentage	"death percentage" Runs: Current	death percentag	"population" Runs: Current	population
0		0.04875		0.407692		4000
1		0.0760462		0.297249		2564.23
2		0.0976456		0.253617		1997.02
3		0.11569		0.229657		1685.54
4		0.130571		0.21488		1493.44
5		0.142593		0.205195		1367.53
6		0.15		0.198609		1281.92
7		0.15		0.194025		1222.32
8		0.15		0.190782		1180.16
9		0.15		0.188462		1150.01
10		0.15		0.18679		1128.27
11		0.15		0.185579		1112.52
12		0.15		0.184697		1101.06
13		0.15		0.184054		1092.7
14		0.15		0.183583		1086.58
15		0.15		0.183239		1082.11
16		0.15		0.182986		1078.82
17		0.15		0.182801		1076.41
18		0.15		0.182665		1074.64
19		0.15		0.182565		1073.34
20		0.15		0.182491		1072.39
21		0.15		0.182437		1071.69
22		0.15		0.182398		1071.17
23		0.15		0.182369		1070.79
24		0.15		0.182347		1070.51
25		0.15		0.182331		1070.31
26		0.15		0.18232		1070.16
27		0.15		0.182311		1070.05
28		0.15		0.182305		1069.96
29		0.15		0.1823		1069.91

Figure 10: The birth rate and death rate of squid with N=4000 and K=1300 with final population growth model

We can see from testing the final model that it can predict when the fish population will reach its carrying capacity. We ran the model with the initial fish population at more than carrying capacity to ensure that the birth and death rates adjusted proportionally. The results matched the predicted performance. We successfully performed the testing of an offset between N (population) and K (carrying capacity) at equilibrium.

To see how birth and death influences function when the population reaches the carrying capacity, we expanded the initial population from 100 to 4,000. We also raised the carrying capacity from 1,000 to 1,500 to see how birth and death fractions change and how population growth works.

Sensitivity analysis (SA) is the systematic variation of input parameters and cataloguing of how the critical output indicator respond in order to determine which input parameter must be further verified and to assess if the response to change is reasonable [2], [54], and [55]. When it comes to sensitivity analysis, we have taken a few steps to look at population growth and equilibrium.

5 CONCLUSION

We introduced a system dynamic model in this article that illustrates how system dynamics modelling can assess options for improving fish population growth. We used a few equations that suited real-world population observations to correctly measure the complex behaviour of fish birth, death, and harvest in our model. The birth and death variables and the growth of the fish population are correctly estimated using our equations and built-in functions in this model. In terms of birth and death fractions and population increase, the feedback loop behaved as expected. It was controlling both birth and death fractions, as well as population rise, using an algorithm.

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