Thesis for the Degree of Masters of Fisheries Science

Behavior analysis of the tuna longline gear for improved performance and efficiency in Fiji

by

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KOICA-PKNU International Graduate Program of Fisheries Science

Graduate School of Global Fisheries

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향상된성능과효율성을위해피지에서참치연승기어의행동분석

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Abstract

In this study, a numerical method and the catenary curve system of analyzing longline fishing gear was used to assess the performance and improve the efficiency of the tuna longline fishing gears in Fiji. The results showed that the analyzing methods used in Fiji was inefficient and did not provide accurate and realistic longline mainline and hook depth data. The SimuLine computer software and the Korean displacement analysis method provided more dependable mainline and hook depth data because they considered the principles of the mass spring model within their calculations. An improved understanding of the relationship between the effects of ocean currents and the configuration of longline gear (the shortening ratio, number of hooks) was the outcome. These factors affect the mainline and hook depth of longline gears which finally influence the selectivity of offshore fish species and the degree of damage to the offshore marine environment. Application of these results will lead to an improved and efficient offshore fisheries industry in Fiji.

Keywords: numerical methods, mainline depth, fishing gear, tuna longline, mass spring model, efficiency.

1.0. Introduction

1.1. The offshore fisheries sector in Fiji

1.1.1. The tuna longline fishing industry

The tuna longline fishing industry is very important to the Fiji Government since it was established by the Ministry of Fisheries in 1977. Fiji is located within the Western Central Pacific fishery which represents a critical store of "natural capital" for economic growth in Fiji and other pacific small island developing states (Ravitu, 2014). The Fiji Economic Exclusive Zone, EEZ, provides good catches of albacore and other offshore pelagic species where the predominant fishing method is long lining (Amoe, 2002). The fisheries sector employs a large number of people, the fish provides an endless source of nutrition and sustenance to the diet of the local people and the fisheries are cherished for both its recreational and traditional aspect's (Gillet, 2011). The use of longline is being encouraged by fisheries management authorities for its conservation orientated aspects. The fuel consumption is low, fishing grounds are not damaged, the fish are captured with good quality and discards of undersized fish and non-target species are low (Lokkeborg and Bjordal, 1992). Although the longline design has evolved over centuries and its catch performance has been improved through gear improvement programs, there is still potential for improving catch efficiency and selectivity (Lokkeborg and Bjordal, 1992). A 2005 Fiji Fisheries Sector Review report estimated the Fiji fisheries contribution at FJD78.4 million (USD43.7 million) to the Fiji Islands economy. The report noted an estimated 6847 Fijians were engaged in either commercial or subsistence fishing, furthermore, the total economic contribution of the fisheries sector was estimated at FJD91.9 million (USD51.49 million) or 2.5% of the total GDP (Hand et al. 2005).

1.1.2. Challenges faced by the tuna fisheries industry in Fiji

The FAO offshore tuna catch data confirms that Fiji has been struggling to consistently harvest maximum catches of targeted offshore tuna fish species. The catch per unit effort of tuna species registered in 2001 has been fluctuating until 2011. The catch rate of offshore tuna species in Fiji has remained steady for the last 5 years, according to FAOs offshore fisheries catch data, (WCPFC, 2014). The necessity for improving the fishing efficiency of tuna longline gear in Fiji should be a priority for the Fiji Government if the tuna industry in Fiji is to keep consistently harvesting tuna fish species. The current offshore fishing technology that is available with the domestic long line fishing fleets in Fiji was adopted directly from overseas long line vessels that fish within Fijis EEZ without any proper research and trials. Proper application and research on longline fishing gears have not been fully done to plan the best longline gear that is applicable for Fiji’s long line domestic vessels. Low catch rates of tuna species are induced by numerous factors but the low capacity into fishing gear developments is one of the major factors that affect the catch rate of tuna species for longline fishing vessels in Fiji. Obtaining the proper shape and hook depth of the longline gear requires fishing gear modeling research and computer software's that can test and certify the stiffness of the longline fishing gears. The Fiji Fisheries sector does not have access to the resources that can improve the performance of the longline gears that are used by the local offshore fishing vessels. The application of inappropriate fishing gear model techniques has caused the inconsistent catch rates of tuna fish species and misleading information on longline fishing is being used in Fiji and also in other Pacific Island countries.

1.2. Previous research that has been on-going to help the offshore fisheries industry in Fiji

Non-governmental organizations, NGOs, present in the South Pacific region have always assisted small island states, like Fiji, to manage and conserve the tuna resources in their respective EEZ. The Secretariat of the Pacific Community, SPC, the Western and Central Pacific Fishery Commission, WCPFC, and the Food and Agricultural Organization, FAO, to name a few, are the main regional agencies operating in the Pacific region. Technical reports about offshore tuna stock levels and future trends have been published and management programs have been conducted to build the capacity of fisheries officials. Training manuals have been published to help offshore fishers prepare properly and obtain the proper gear for offshore tuna fishing. Consultations and advice have been coming from the regional non-government organizations to the central governments regarding the use of the EEZs of the respective Pacific Islands. Smart policies that need to be regularized by governments have been proposed to allow maximum sustainable management of the offshore fish species and allow the availability of tuna species for the future generations.

1.3. Research using numerical methods to improve the efficiency of offshore fishing gear

A study conducted by Lee et al. 2005b, proposed the mathematical interpretation of longline fishing gear by using the mass spring model. The mathematical interpretation was then coded into computer programs to allow the dynamic simulation of longline fishing gears. The SimuLine computer software was developed by the Marine Production System laboratory, Marine Production Management Division, Pukyong National University, Busan, Korea. Longline design file was converted by SimuLine software and simulated in the computer (chip intel (R) core (TM) 2 Quad CPU Q8200 @2.33GHz, RAM 3.00GB) at the Department of Fisheries Physics, Graduate School, Pukyong National University.

The mass spring model is explained through vector analysis of both the internal and external forces acting on the longline fishing gear. The internal force was considered as the force on the mass points with the external force. The internal force equations will consider the elasticity of the lines of the fishing gear while the external force will consider gravitational, resistance and buoyancy and other forces on the longline fishing gear. Without considering the elasticity of the line, the only forces included in the theoretical model are external forces. Therefore, the mathematical model is simply explained in comparison, but dynamic analysis and simulation are inaccurate and not realistic.

The ability to conduct computer-based dynamic simulations has allowed fishing gear scientist to observe and manipulate the shape of tuna longline gear by changing the sea conditions and gear rigging. Computer – based longline simulation of longline gear has allowed computer modeling of long line fishing gear and analysis to be done according to the specified directions and velocity of the ocean current. Computer – based longline simulation results show the different restructuring effect on the long line fishing gear when exposed to different underwater current velocities and directions respectively. This knowledge will allow maximum bait usage for targeted tuna species and a decrease in the level of harvesting protected fish species or by-catch fish species. Computer – based longline simulation have been compared to longline experiments conducted in a flume tank and the results showed low percentages, 0.l – 3%, of variation rates, according to Lee et al. 2005b. Computer – based longline simulation technology will allow the global tuna industry to efficiently use tuna fish resources with less impact on other non-targeted fish species and the marine environment.

1.4. Objectives

The purpose of this study is to:

- ❖ Calculate mainline depth data from the computer-based longline simulation trials and from the Korean Displacement analysis at equilibrium (ocean current at 0m/s).
- ❖ Compare the longline main line depth data that was published in Offshore fishing manuals by the Secretariat of the Pacific Community, SPC, in Fiji to the longline mainline data computed from the computer – based longline simulation trials and mainline depth data calculation from the Korean displacement analysis.

2.0. Methods and Materials

2.1. Numerical Method of analyzing longline fishing gear

2.1.1. Computer based longline simulation software

Tuna long line gear used for this research has 20 baskets for each set. The minimum number of mass points in a basket is 250, so the total number of an entire gear configuration is approximately 12,500 points. With so many points used for this analysis, it is difficult to calculate all of the points on a long line gear configuration. However, a longline gear basket is made up of a mainline and branch lines, each of which has an identical length. Also, each basket is identical so the results of the calculation of a reduced number of selected baskets can be applied to all other baskets. Using operational condition at sea, all of the baskets were divided into 3 sections, and the movement of the fishing gear simulated according to the results of the calculations of five baskets in each section. This method of mathematical interpretation follows the Newmark β method ($\alpha = 0$, $\beta = 0.25$, $\gamma = 0.5$), which is known to be generally stable and time efficient, (Lee et al. 2005b).

2.1.2. Model of fishing gear system

The mass spring model makes it possible to derive a model of a fishing gear system because it is modeled differently according to the elasticity of the line connecting each mass point. Without considering the elasticity of the line, the only forces included in the theoretical model are external forces such as gravity, resistance, sheer force, and buoyancy. Therefore, the mathematical model is simply explained in comparison of the external forces, but dynamic analysis and simulation are inaccurate and not realistic, (Lee et al. 2005b).

Figure 1. Longline gear in coordinate system

(Source: Lee et al. 2005b)

Considering the elasticity of the line, the model becomes a stiff equation that is complicated and difficult to calculate, however, it makes dynamic analysis and simulation more accurate and realistic. This is a derived mathematical model with respect to the elasticity of the rope connecting each mass point that is the mass-spring model in physics, (Lee, 2002).

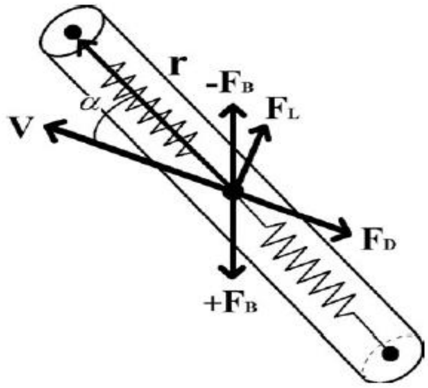

Figure 2. The Mass Spring Model : Forces acting on the rope element, the F_B, buoyancy force, F_L, lift force, F_D, drag force**, r**, position vector between neighboring mass points, **V**, velocity vector, α, the angle of attack.

(Source: Lee et al. 2005b)

The theoretical mathematical model of a fishing gear system is generally considered as a physical system in which each element forming the fishing gear is divided into finite numbers of mass points and those points are connected with flexible lines, (Lee, 2002). In detail, describing the elements of a fishing gear system in a generalized coordinate system, described with the equations of motion, (Lee et al. 2005b).

The equations of motion, according to Lee et al. 2005, can be described as:

$$m\ddot{\boldsymbol{q}} = \Sigma \mathbf{f} \quad (1)$$

Where m is the total mass, $\ddot{\boldsymbol{q}}$ is the acceleration vector and **f**, is the sum of the forces acting on the mass point.

$$\mathbf{f}_{int} = -k\mathbf{n}(|\mathbf{r}| - l^0) \quad (2)$$

Where, k is the stiffness of the line, **n** is the unit vector along the line of the spring, **r** is the positive vector between the neighboring mass points and l^0 is the original spring length. The unit vector **n** may be obtained by dividing the vector **r** by its magnitude $|\boldsymbol{r}|$. The force $\mathbf{f}_{int}$ is proportional is proportional to the displacement of the spring measured from the original length, and $\mathbf{n}(|\mathbf{r}| - l^0)$ is the displacement in three dimensional space. Some external forces, which represent the interaction of mass points with the environment, include drag, lift, buoyancy and sinking forces. The forces on the bar are shown in Figure 2. The drag that acts on the mass points is a decisive factor in shaping fishing gear when it is launched into the water or is set. The drag can be described as:

$$\mathbf{F}_{D} = \frac{1}{2} C_D \rho S V^2 \mathbf{n}_v \quad (3)$$

Where, C_D is the coefficient of drag, ρ is the density of the fluid, S is the projected area of the structure, and V is the magnitude of the resultant velocity vector **V**. The resultant velocity vector consists of the velocity of the mass point and current velocity vector. $\mathbf{n}_v$ is the unit vector for drag and acts in the inverse direction of the resultant velocity vector. The angle of attack α, between the velocity vector **V** and the position vector **r** should be determined in order to decide the coefficient of drag. The attack angle is determined by:

$$\alpha = \cos^{-1}\left[\frac{\mathbf{V} \cdot \mathbf{r}}{|\mathbf{V}||\mathbf{r}|}\right] \quad (4)$$

The sheer force is;

$$\mathbf{F}_L = -\ \frac{1}{2} C_L \rho S V^2 \mathbf{n}_L \qquad (5)$$

Where, C_L is the coefficient of sheer force, determined by the angle α, and ρ, S, V are as previously defined. The most important factor in the formulae of lift force is the direction of operation $\mathbf{n}_L$ because force works at 90° to the drag. The direction of operation of lift forces for each element is obtained by the vector product $\mathbf{V} \times (\mathbf{V} \times \mathbf{r})$ and the unit vector $\mathbf{n}_L$ of this direction is expressed as:

$$\mathbf{n}_L = \frac{\mathbf{V} \times (\mathbf{V} \times \mathbf{r})}{|\mathbf{V} \times (\mathbf{V} \times \mathbf{r})|} \qquad (6)$$

Where $|\mathbf{V} \times (\mathbf{V} \times \mathbf{r})|$ is the magnitude of this vector.

The drag coefficient and lift coefficient were derived by experiments that synthesized the trawl system with an actual gear. Experiments with models in a flume tank have been performed in our laboratories and by other researches. The coefficient of the drag and lift force for the element used in this paper is shown by Figure 3.

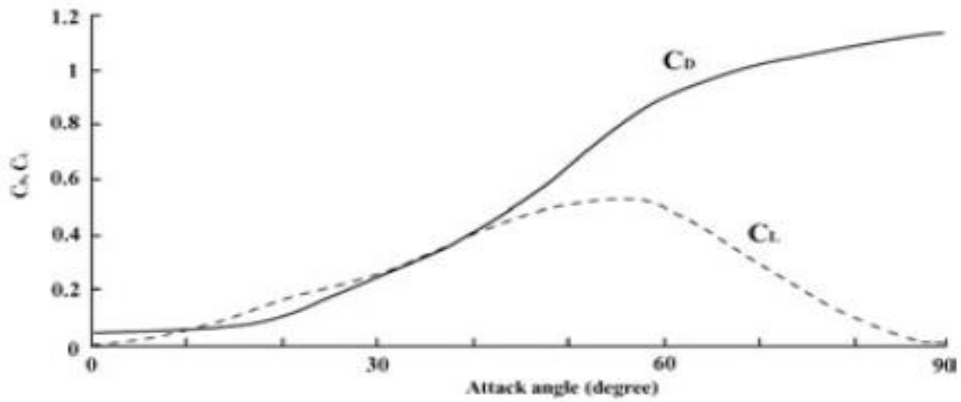

Figure 3. Drag (C_D) and lift (C_L) force coefficients for the rope as a function for the angle of attack.

(Source: Lee et al. 2005b)

The buoyancy and sinking force of the structures F_B can be described as:

$$\mathbf{F}_{\boldsymbol{B}} = (\rho_i - \rho_w)V_N\mathbf{g} \qquad (7)$$

Where ρ_i is the density of the material, ρ_w is the density of the seawater, V_N is the volume of the elements and **g** is the acceleration due to gravity. The additional mass, m_a of the structure is given by;

$$m_a = \rho_w V_N \qquad (8)$$

Where ρ_w is the density of the seawater, and V_N is the volume of the element.

2.2. The Catenary Curve method

2.2.1. Korean Displacement Analysis design (KDA)

The catenary curve is a uniform curve, an inextensible line that hangs between two fixed points, which are at the same level. The elements of the line are assumed to be perfectly flexible and it is further assumed that the cable can also sustain tension force, (Irvine, 1981).

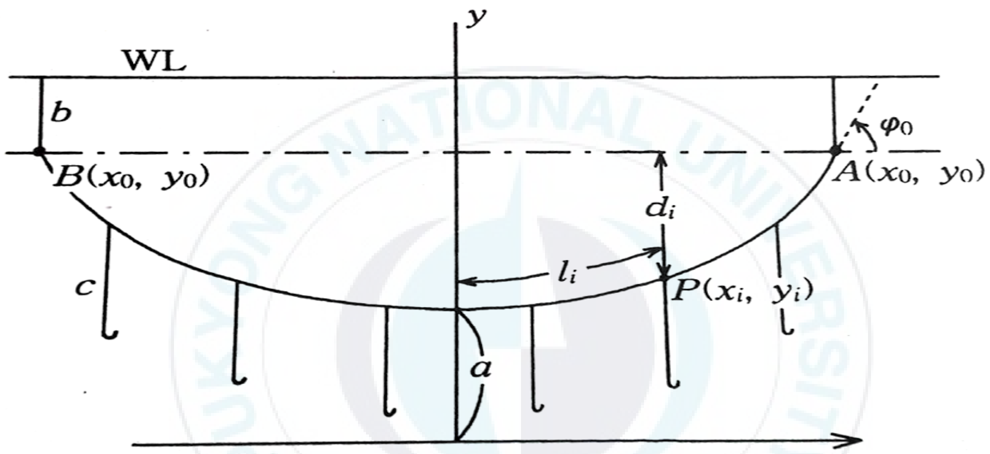

Figure 4. Design of the Korean displacement analysis, KDA, for the longline fishing gear.

(Source: Kim, 1999)

The equation to determine the mainline depths, according to Kim, 1999, is described as:

$$d_i = l_0\{\text{cosec}\ \varphi_0 - \sqrt{(\frac{l_i}{l_0})^2 + \cot^2 \varphi_0}\} \qquad (9)$$

Where *di* – distance from the bottom of the buoy line to the deepest point of the mainline, *lo* – half the length of the mainline at full stretch, *li* – initial point, cosec φ_0, $\cot^2 \varphi_0$ – shortening ratio constants.

$$K = \frac{xo}{lo} \tag{10}$$

Where *K* – Shortening ratio, *xo* – horizontal distance of the buoy from the center of the longline basket at full stretch, *lo* – half the length of the mainline at full stretch. According to Hamuro and Ishii, 1958, the shortening ratio is also estimated by the ratio of vessel speed to the mainline setters releasing the speed.

2.3. Secretariat of the Pacific Community analysis method

2.3.1. Pythagorean Theorem analysis

Pythagorean Theorem — 'The Square of the hypotenuse of a right-angle triangle is equal to the sum of the square of the two sides, (Beverly et al. 2003). Fishing gear scientist at the Secretariat of the Pacific Commission, SPC, used the Pythagorean Theorem principal to calculate the mainline depth, A, with the use of actual fishing gear data recorded by the domestic longline vessels in Fiji and other Pacific Island countries

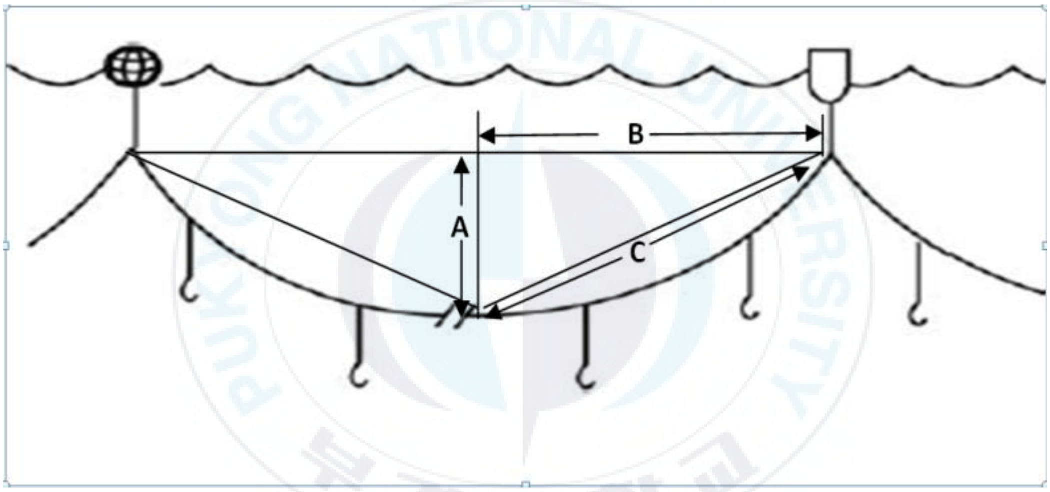

Figure 5. Dimensions for the Pythagorean Theorem analysis for longline fishing gears

(Source: Beverly et al.2003)

The Pythagorean Theorem equations, according to Beverly et al. 2003, are described as:

$$A^2 + B^2 = C^2 \quad (11)$$

Where A, is the mainline depth (this length represents the distant between the lowest points of the buoy line to the deepest point of the mainline, at full stretch) B is half the distance the boat travels between two buoys, and C is half the length of line between two buoys.

$$C = ½ \text{ x } L \quad (12)$$

Where L, is the *main line length between* the 2 buoys.

$$B = S \text{ x } t \quad (13)$$

Where S, is the Vessel Speed (m/min), t, time (min) taken for the boat to travel between 2 buoys.

$$A = \sqrt{(C^2 – B^2)} \quad (14)$$

Where B, is half the distance the boat travels between buoys, C, is equivalent to half the mainline length of the longline basket.

Longline Hook Depth = A+ FL+ BL (15)

Where A, is the mainline depth, BL, Buoy line length, BL, branch line length at full stretch.

2.3.2. Secretariat of the Pacific Community – Mainline depth data

The calculated longline mainline depths represented in Table 1 have been reduced by 20 percent. The length of the float line and length of branch line needs to be added to the depth of mainline to give the hook depth of the longline gears. The mainline depths was achieved and calculated with the Pythagorean Theorem analysis equation. The proposed specification of the longline: 50m for the distance between the branch lines, 30m buoy line length, 20m branch line length, vessel speed of 7 knots and the ocean current speed is not considered for the analysis.

Table 1. Theoretical longline mainline depths based on different shortening ratio (SR) and basket sizes, proposed by the Secretariat of the Pacific Community analysis method.

Basket size (No of hooks)	Shortening Ratio - 0.7	Shortening Ratio - 0.8	Shortening Ratio – 0.9
10	155 m	130 m	95 m
15	230 m	190 m	140 m
20	300 m	250 m	185 m
25	370 m	310 m	230 m
30	445 m	370 m	270 m

(Source: Beverly et al. 2003)

2.4. Experimental design

Comparative analysis of the relative mainline depth data, in Table 1, from the Secretariat of the Pacific Community, with the SimuLine computer software and Korean displacement analysis calculated mainline depth data. Table 1, shows the mainline depth, according to Beverly et al. 2003, that was calculated by using the Pythagorean Theorem analysis method. The data includes the shagging ratios, the size of baskets, the spacing between two hooks and the main line depths.

2.4.1. SimuLine computer software design

The longline fishing gear specifications in Table 2 to Table 11 are the actual longline gears used by longline fishing vessels in Fiji. This information was very important for the preparation of the computer - based longline simulation program for the current research. The longline gear specifications were coded into the SimuLine computer software by the skilled programmer for the Marine Production System laboratory, Marine Production Management Division, Pukyong National University.

The computer - based long line gear simulation trials was performed through the SimuLine computer software from the College of Fisheries Science computer laboratory, Pukyong National University. The longline fishing gear simulation trials was carried out 3 times with a step size of 0.002s, according to the different shortening ratios, for each basket sizes at an ocean current speed of 0m/s. The specification of the longline gear used in the research: 50m for the distance between the branch lines, 30m buoy line length, 20m branch line length and a vessel speed of 7knts.

2.4.2. Korean displacement analysis

The Korean displacement analysis is based on catenary curve principles in which the whole longline system is in equilibrium so that the system is at a fixed position. According to the mainline depth equation proposed by Kim, 1999, the mainline depths of the longline gears were calculated with their respective shortening ratios. The length of the mainline, the shortening ratios and the angle at which the mainline curve make with the water level were vital information to calculating the longline gear mainline depths. The calculations were carried out 3 times, according to the different shortening ratios for each basket sizes. The specification of the longline gear used in the current research: 50m for the distance between the branch lines, 30m buoy line length and 20m branch line length.

2.5. Longline gear specification – Simulation trials

Table 2. Specification for longline fishing gear for Simulation I

Part	Material	Diameter (mm)	Length (m)	Weight (kg)	Buoyancy (N)	Number	Density (kg/m^3)
Mainline	Nylon Monofilament	3.5	11,000				
Buoy line	Tarred red polyester	6.4	30			25	1.4
Snood (branch line)	Nylon Monofilament	1.5	20			200	
Radio beacon buoy line	Tarred red polyester	6.4	50				1.4
Buoy	Hard Plastic	360		3.9	30	25	
Radio Beacon		410	0.84 height	20.5	157	2	
Hook	Tuna Circle Hook	4.1	0.08 height	0.0154	0.02	200	

(Number of baskets: 20, Number of Hooks: 10 per basket, Spacing between hooks 50m, Length of Mainline per basket: 550m)

Table 3. Distance between buoys per basket for Simulation I

Shortening Ratios	Distance between buoys per longline basket (m)
0.7	385
0.8	440
0.9	495

Table 4. Specification for long-line fishing gear for Simulation II

Part	Material	Diameter (mm)	Length (m)	Weight (kg)	Buoyancy (N)	Number	Density (kg/m³)
Mainline	Nylon Monofilament	3.5	16,000				
Buoy line	Tarred red polyester	6.4	30			25	1.4
Snood (branch line)	Nylon Monofilament	1.5	20			300	
Radio beacon buoy line	Tarred red polyester	6.4	50				1.4
Buoy	Hard Plastic	360		3.9	30	25	
Radio Beacon		410	0.84 height	20.5	157	2	
Hook	Tuna Circle Hook	4.1	0.08 height	0.0154	0.02	300	

(Number of baskets: 20, Number of Hooks: 15 per basket, Spacing between hooks: 50m, Length of Mainline per basket: 800m)

Table 5. Distance between buoys per basket for Simulation II

Shortening Ratios	Distance between buoys per longline basket (m)
0.7	560
0.8	640
0.9	720

Table 6. Specification for longline fishing gear for Simulation III

Part	Material	Diameter (mm)	Length (m)	Weight (kg)	Buoyancy (N)	Number	Density (kg/m^3)
Mainline	Nylon Monofilament	3.5	21,000				
Buoy line	Tarred red polyester	6.4	30			25	1.4
Snood (branch line)	Nylon Monofilament	1.5	20			400	
Radio beacon buoy line	Tarred red polyester	6.4	50				1.4
Buoy	Hard Plastic	360		3.9kg	30	25	
Radio Beacon		410	0.84 height	20.5kg	157	2	
Hook	Tuna Circle Hook	4.1	0.08 height	0.0154	0.02	400	

(Number of baskets: 20, Number of Hooks: 20 per basket, Spacing between hooks: 50m, Length of Mainline per basket: 1050m)

Table 7. Distance between buoys per basket for Simulation III

Shortening Ratios	Distance between buoys per longline basket (m)
0.7	735
0.8	840
0.9	945

Table 8. Specification for longline fishing gear, Simulation IV

Part	Material	Diameter (mm)	Length (m)	Weight (kg)	Buoyancy (N)	Number	Density (kg/m^3)
Mainline	Nylon Monofilament	3.5	26,000				
Buoy line	Tarred red polyester	6.4	30			25	1.4
Snood (branch line)	Nylon Monofilament	1.5	20			500	
Radio beacon buoy line	Tarred red polyester	6.4	50				1.4
Buoy	Hard Plastic	360		3.9	30	25	
Radio Beacon		410	0.84 height	20.5	157	2	
Hook	Tuna Circle Hook	4.1	0.08 height	0.0154	0.02	500	

(Number of baskets: 20, Number of Hooks: 25 per basket, Spacing between hooks: 50m, Length of Mainline per basket: 1300m)

Table 9. Distance between buoys per basket for Simulation IV

Shortening Ratios	Distance between buoys per longline basket (m)
0.7	931
0.8	1064
0.9	1197

Table 10. Specification for longline fishing gear for Simulation V

Part	Material	Diameter (mm)	Length (m)	Weight (kg)	Buoyancy (N)	Number	Density (kg/m^3)
Mainline	Nylon Monofilament	3.5	31,000				
Buoy line	Tarred red polyester	6.4	30			25	1.4
Snood (branch line)	Nylon Monofilament	1.5	20			600	
Radio beacon buoy line	Tarred red polyester	6.4	50				1.4
Buoy	Hard Plastic	360		3.9kg	30	25	
Radio Beacon		410	0.84 height	20.5kg	157	2	
Hook	Tuna Circle Hook	4.1	0.08 height	0.0154	0.02	600	

(Number of baskets: 20, Number of Hooks: 30 per basket, Spacing between hooks: 50m Length of Mainline per basket: 1550m)

Table 11. Distance between buoys per basket for Simulation V

Shortening Ratios	Distance between buoys per longline basket (m)
0.7	1085
0.8	1240
0.9	1395

3.0. Results

3.1. Longline gear analysis and hook depth graphical analysis

3.1.1. Longline mainline depth data

The mainline depth data, shown in Table 12, were calculated at 0.7, 0.8 and 0.9 shortening ratio's against five basket sizes for the simulated longline trials, SLG, the Korean displacement analysis, KDA, and the SPC – Pythagorean Theorem analysis. The longline hook depths, in Table 12, shows the total mainline depth of the longline fishing gears when the ocean currents are not considered in the calculations or analysis.

Table 12. Comparative analysis of the Secretariat for the Pacific Community longline mainline depth data, the simulated longline mainline depth data and the Korean displacement analysis longline gear mainline depth data.

No of Hooks	Longline Gear - Mainline Depths Data (m)								
	Shortening Ratio – 0.7			Shortening Ratio – 0.8			Shortening Ratio – 0.9		
	SPC	SLG	KDA (0.702)	SPC	SLG	KDA (0.799)	SPC	SLG	KDA (0.909)
10	155	177	176	130	147	146	95	106	99
15	230	264	256	190	218	212	140	154	144
20	300	348	336	250	286	278	185	201	189
25	370	437	416	310	359	345	230	253	234
30	445	470	496	370	435	417	270	304	279

(SPC – Secretariat of the Pacific Community data, SLG - Simulated longline gear data and KDA – Korean displacement analysis data)

3.1.2. Longline hook depth data

The hook depth data in Table 13 was calculated by the addition of the float line length and branch line with the mainline depth in Table 12, for the simulated longline trials, SLG, the Korean displacement analysis, KDA, and the SPC – Pythagorean Theorem analysis. The longline hook depths, in Table 13, shows the total hook depth of the longline fishing gears when the ocean currents are not considered in the calculations or the analysis.

Table 13. Comparative analysis of the Secretariat for the Pacific Community longline hook depth data, the simulated longline hook depth data and the Korean displacement analysis longline gear hook depth data

No of Hooks	Longline Gear -Hook Depths Data (m)								
	Shortening Ratio – 0.7			Shortening Ratio – 0.8			Shortening Ratio – 0.9		
	SPC	**SLG**	**KDA** (0.702)	**SPC**	**SLG**	**KDA** (0.799)	**SPC**	**SLG**	**KDA** (0.909)
10	205	227	226	180	197	196	145	156	159
15	280	314	306	240	268	262	190	204	194
20	350	398	386	300	336	328	235	251	239
25	420	487	466	360	408	395	280	303	284
30	495	520	546	420	485	461	320	354	329

(SPC – Secretariat of the Pacific Community data, SLG - Simulated Longline Gear data and KDA – Korean Displacement Analysis data)

3.1.3. Longline gear shortening ratio analysis

Comparative analysis of the different shortening ratio operated by the simulated longline gear trials, SLG, the Korean displacement analysis, KDA, and the SPC – Pythagorean Theorem analysis.

Table 14. Shortening ratios for the Secretariat for the Pacific Community analysis, Korean displacement analysis and the computer based longline simulation trials

Shortening Ratio (SR)									
	Shortening Ratio – 0.7			**Shortening Ratio – 0.8**			**Shortening Ratio – 0.9**		
No. of Hooks	**SPC**	**SLG**	**KDA**	**SPC**	**SLG**	**KDA**	**SPC**	**SLG**	**KDA**
10	0.8	0.7	0.7	0.9	0.8	0.8	1.0	0.9	0.9
15	0.8	0.7	0.7	0.9	0.8	0.8	1.0	0.9	0.9
20	0.8	0.7	0.7	0.9	0.8	0.8	1.0	0.9	0.9
25	0.8	0.7	0.7	1.0	0.8	0.8	1.0	0.9	0.9
30	0.7	0.7	0.7	0.9	0.8	0.8	1.0	0.9	0.9

(SPC – Secretariat of the Pacific Community, SLG - Simulated Longline Gear and KDA - Korean Displacement Analysis)

3.1.4. Graphical representation for the longline gear hook depth data

The graphs represents the hook depth data in Table 13 for the simulated longline gear trials, SLG, the Korean displacement analysis, KDA, and the SPC – Pythagorean Theorem analysis at the respective shortening ratios and basket sizes. The hook depths represent the depth of the longline fishing gears when the ocean current is at equilibrium state.

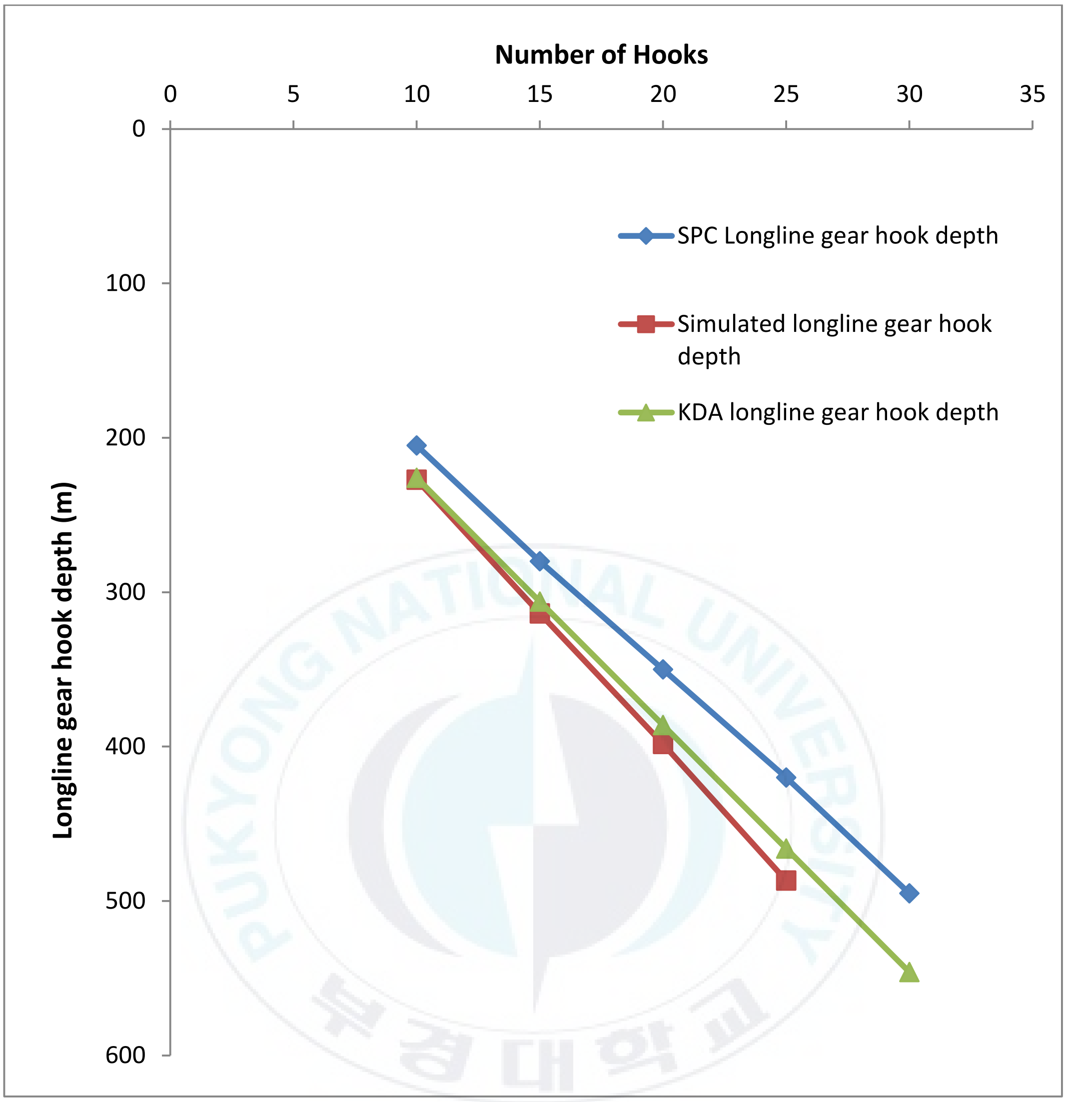

Figure 6. The SPC, Simulated longline and KDA longline fishing gear hook depth data at 0.7 shortening ratio

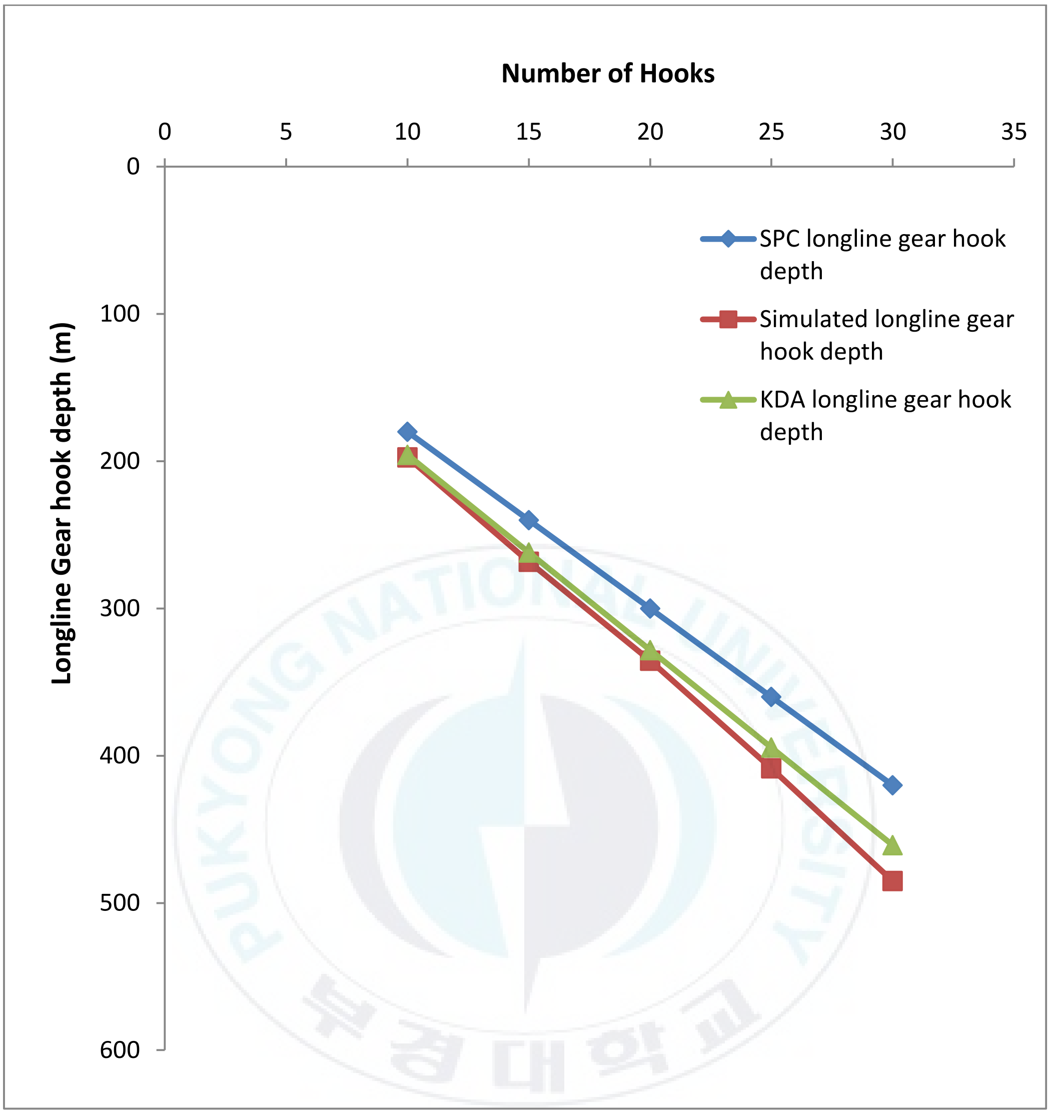

Figure 7. The SPC, Simulated longline and KDA longline fishing gear hook depth data at 0.8 shortening ratio

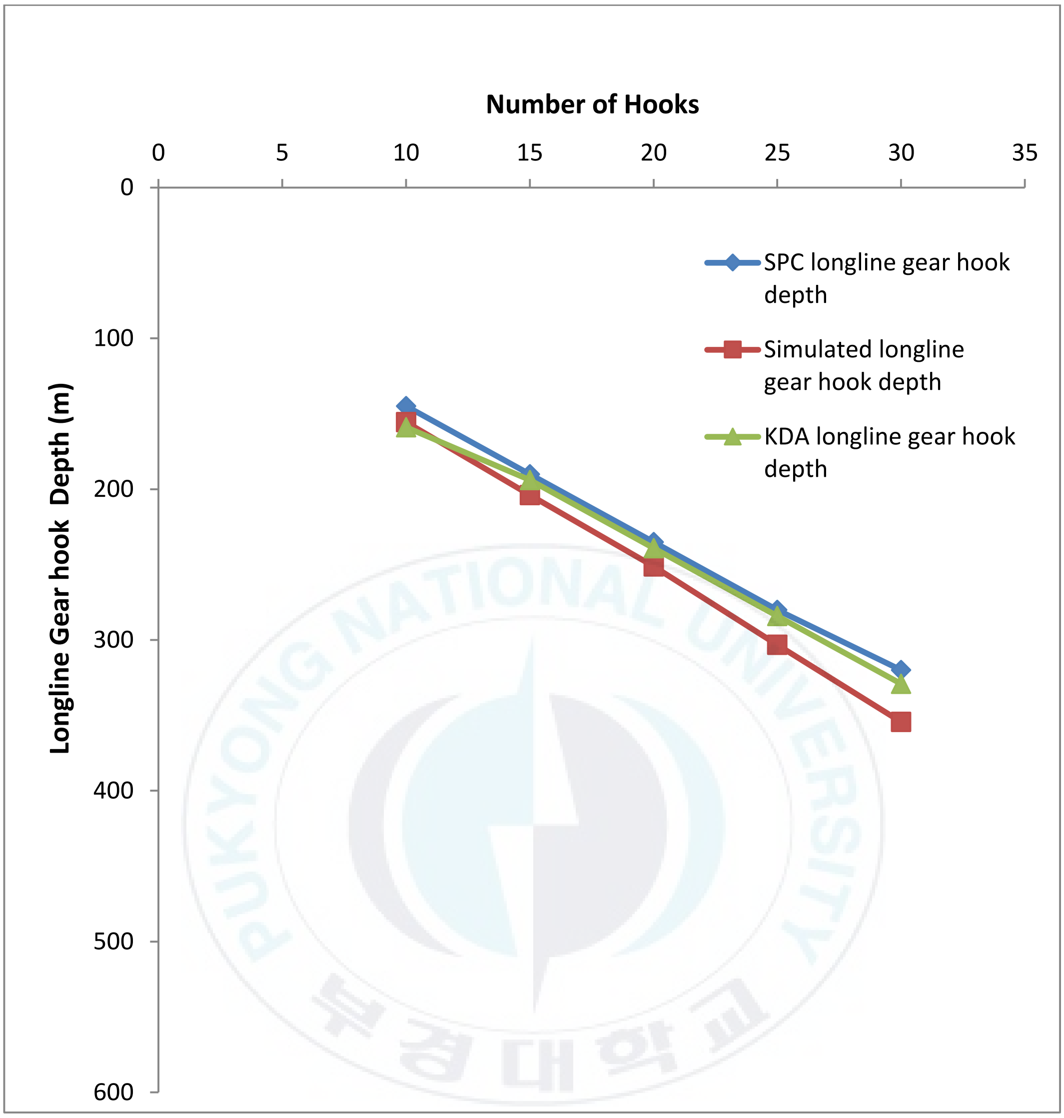

Figure 8. SPC, Simulated longline and KDA longline fishing gear hook depth data at 0.9 shortening ratio.

4.0. Discussion

4.1. Numerical Method of analyzing the tuna longline fishing gear

4.1.1. SimuLine computer software

Fishing gear systems and aquaculture facilities are generally considered as flexible system in which various structures are connected with elastic lines. A physically based calculation model to simulate the flexible structures behavior is presented in order to understand the movements and design of an appropriate system, (Lee et al. 2005b). According to Lee et al. 2005a, the Newmark – β method suggested for this study allows a much faster calculation than the Runge – Kutta method and can be appropriate for stiff equations as its algorithm is an explicit one. Moreover, it is a method to solve the second order differential equation directly with reducing the order, making it easier to mechanize the calculation process.

The longline simulation software is based on the principle of the mass spring model, involving the participation of both the internal and external forces on a longline fishing gear.

The mass spring model allows the longline fishing gear to be modeled according to the elasticity, internal force, of the line connected to the mass points on the fishing gear. If the elasticity of the line is not considered, the only forces that will be used to model the fishing gear will be the external forces such as gravity, resistance, sheer force and buoyancy force. Consideration of both the internal and external forces produces a fishing gear model that is complicated and stiff, creating accurate and realistic computer-based longline simulations.

4.1.2. Computer-based longline simulation trials

The simulated mainline depths increased uniformly as the number of hooks increase for all the three specified shortening ratios. The mainline depth was very high for the 0.7 shortening ratio and very low for the 0.9 shortening ratio. Since the longline simulation trials were conducted at an ocean current of 0 m/s, only the weight and gravity of the longline fishing gears were probably supplying the external and internal forces on the fishing gear to provide the resultant mainline depths in Table 12, for the longline simulation trials.

The calculated mainline and hook depths data provided in Table 12 & Table 13 may not be applicable and realistic for actual fishing operation but the results can give an exact location of the longline fishing gear in a resting position or at equilibrium. Therefore, hook depth changes according to the velocity and direction of the ocean currents, (Lee et al. 2005b). The consideration of ocean currents will supply both the internal and external forces on the longline fishing gears and cause a reduction in the values of the mainline and hook depth data shown in Table 12 & Table 13 respectively. The longline simulation trials were providing accurate and reliable data because the SimuLine computer software was efficiently considering other factors like the weight of the fishing gear and gravity since the ocean current is not considered in the current research. These factors are not considered by the Korean displacement analysis method and the Pythagorean Theorem equation because of limitations that are present within their longline gear analyzing methods. Designing a fishing gear system is accomplished by trial and error in order to get the desired performance when the effectiveness is not satisfactory after analyzing and inspecting the performance of a tentatively designed system for modeling fishing gears (Lee et al. 2005a).

Additional information for improving the performance and efficiency of longline fishing gears from the SimuLine computer software also include the following:

i. Determining the shape of fishing gears at controlled ocean currents, current angles, wave lengths, wave angles, and ocean depths.
ii. Estimated time scale for the deploying and hauling process of the longline fishing gears at specified oceanic conditions.
iii. Conduct numerous accurate and realistic fishing gears simulation indoors.

4.1.3. Mass Spring Model

The computer-based simulation program was able to produce the accurate mainline depth, shown in Table 12, because of the ability of the longline simulation software to create a realistic representation, through the mass spring model, of the fishing gear movement from deploying process until the hauling process of a longline gear. This allowed analysis to be completed at exactly the suitable shortening ratio and produce accurate mainline and hook depths results. A research conducted by Lee, 2002, explained that the force vector at each mass point of a fishing gear is described individually as the internal and external force. In the fishing gear system model, the internal force should be considered as the force on the mass points with the external force. The external force is of various kinds of loads that act on the mass points like gravity, drag, buoyancy, etc. When both the internal and external forces on a fishing gear are considered, the dynamic analysis of fishing gear models and fishing gear simulations become more accurate and realistic

4.2. Cable Structures

4.2.1. Catenary Curve principles

A catenary curve is a uniform curve, an inextensible line that `hangs between two fixed points. The elements of the line are assumed to be perfectly flexible, (Irvine, 1981). The catenary curve is assumed to be flexible and elastic. This is a property that is also exploited by the SimuLine computer software. The catenary curve, however, is located at fixed locations which do not allow all the external forces from the various oceanic conditions to be considered for the calculation of the resultant mainline and hook depths, in Table 12 & Table 13 respectively.

4.2.2. Korean Displacement Analysis, KDA

According to the research conducted by Kim, 1999, the Korean displacement analysis method of calculating longline mainline depths was developed and modeled according to the catenary curve principles. The results in Table 12 shows that the mainline depth data calculated from the Korean displacement analysis increased consistently as the number of hooks increased for all the three applied shortening ratios. The calculated mainline depths were also deepest for the 0.7 shortening ratio and shallow for the 0.9 shortening ratio.

The Korean displacement analysis provided mainline and hook depths data that were relatively close to the mainline and hook depths calculated by the computer-based longline simulation method. The Korean displacement analysis method is normally used to analyze fishing gears in an equilibrium state because the catenary curve is located in a fixed location to replicate a situation where the ocean current is 0 m/s. The consideration of ocean currents in the Korean displacement analysis calculation would cause variable internal and external forces to give lower mainline depths. The catenary curve mainline depth data provides researches with a reference ocean depth to which a longline fishing gear will be in a resting position or at equilibrium.

4.3. Pythagorean Theorem analysis

The Secretariat of the Pacific Community, SPC mainline depth data, in Table 1, was calculated with the Pythagorean Theorem equation, according to (Beverly et al. 2003). The mainline depth data also followed the trends exhibited by the earlier mentioned analyzing methods. The deepest mainline data was shown by the analysis from the 0.7 shortening ratio and the mainline depth was shallow at 0.9 shortening ratio. These common trends can be observed because the analysis of the longline fishing gears was conducted at no ocean currents. The Pythagorean Theorem equation analyzed and approached the longline fishing gear to be a linear moving system, but this is not really the case from a realistic point of view. Table 14, tells us that the shortening rations for the proposed mainline depth values were very high and that produces low mainline depth data, according to Lee et al. 2005. The Pythagorean Theorem is not applicable for the analysis of longline gears because it will mislead fisherman and researchers, also initiate miss guided decisions to be made by countries that rely a lot on the harvesting of offshore tuna resources.

4.4. Dynamic longline fishing gear field research

A longline gear research by Song et al. 2015, from the Shanghai Ocean University, was carried out with an objective to improve simulations of pelagic longline deployment and process of longline settlement also analyze the space shape and tension distribution of longline gear

Measured field data was collected on the 26th of September, 7th of October, 26th of October, 12th of November and 12th of November in 2012, near the Cook Islands, in the South Pacific Ocean. The specifications of the longline gear are the following: 28 hooks, 20.5m branch line, 17m buoy line, line shooter speed was at about 10.5kts and the vessel speed was at approximately 8.5kts. The survey instruments used were the Temperature-Depth Recorders (TDR 2050, RBR Co., Ottawa, Canada) and an Acoustic Doppler Current Profilers (ADCP, Aquadopp, NORTECK Co., Vangkroken, Norway). TDRs were used to measure and record individual hook depths at various positions along the longline. The depth measurement of the TDRs was within ± 0.05% in depths of 10 - 740m. The ADCP was used to measure 3D current data at different depths, with measurement errors within 0.005m/s.

While deploying the longline, TDRs were attached at the end of branch line (replacing the hook) to measure and record the hook depth while settling and final depth. ADCP was used to measure 3D current data at different depths after deployment and the measurement interval between recordings was 10s. ADCP made a measurement at different depths (20m each) and the maximum depth was about 350m. The results of the field research by 3D ocean current analysis, based on the measured data, the current velocities in the Z direction were small, usually less than 0.1m/s while the current velocities in the X and Y direction had obvious differences and showed different variation trends with depth.

According to the gear and vessel specifications of the longline field research conducted by Song et al. 2015, a shortening ratio of 0.8 and a basket size of 30 hooks were also analyzed during the longline field research. Temperature Depth Recorders, TDR, attached to the lowest points of the branch line, located at the center of the mainline, was observed at an average settled depth of 186.28m from four field trials done at consecutive months in 2012, according to the field research conducted by Song et al, 2015. In Table 13 for the current research, the simulated hook depth at the shortening ratio of 0.8 and at a basket size (number of hooks) of 30 was located at 485.05m for the simulated current speed of 0m/s.

The simulated hook depth was reduced from 485.05m to 186.28m by oceanic conditions like drag, buoyancy, shoaling, and gravity being the main factors that affect the depths of longline fishing gears. Mizuno et al. (1997) suggested that there are two major factors which affect the hook depth of longline gears; one is ocean currents and the other is the shortening ratio. It is a common practice to express longline shoaling in terms of a percentage. Boggs (1992) estimated the average percentage of the mainline shoaling at 46% and 32%, respectively for two survey periods. From TDRs deployed on the mainline aboard longline commercial vessels Bigelow et al. (2006) estimated mean shoaling values at about 35% for tuna sets (deep longline configuration) and at 55% for swordfish sets (shallow longline configuration).

Hook depths for longline gears are greatly influenced by the irregular current velocities at different depths, as shown by the Acoustic Doppler Current Profilers in the research conducted by Song et al. 2015. The fluctuation of the gear shape, tension and hydrodynamic forces of the mainline were closely associated with respective ocean current velocities at depths the gear was situated (Song et al. 2015). If the setting time was extended, the distance of the gear's movement in the current direction increases with increased current velocity, (Lee et al. 2005a). The hook depth data, in Table 13, appeared to be increasing uniformly and can be considered as realistic but it is the result when the ocean current is 0m/s, according to the current research.

5.0. Conclusion

Longline gear analysis and relative calculations were successfully completed and the SimuLine computer software was recognized to provide accurate and reliable mainline and hook depth data. The SimuLine computer software longline gear mainline and hook depths, shown in Table 12 and Table 13 respectively, can serve as a reference point for future longline fishing gear field research. The calculated mainline and hook depths, from the longline simulation trials, can be utilized as the depth of the longline fishing gears at resting state or at equilibrium.

The SimuLine computer software is an important tool for the development of efficient longline gears that can maximize the sustainable harvest of offshore targeted fish species with little very impact on the marine environment. The accurate and reliable mainline data provided by the computer based longline simulation trials has been directly through the integration of the mass spring model within the fishing gear analysis of the SimuLine computer software. The mass spring model allows accurate data to be calculated from simulated fishing gears that a rigged in a number of various ways. Apart from the difference in analytical techniques, in the current research, the SimuLine computer software was observed to be perfectly developed and all aspects affecting the longline gear in the ocean was considered in the mathematical gear model analysis to produce accurate and reliable data.

The Korean displacement analysis mainline data was relatively close to the longline simulations trials mainline depths data because both the method of analysis considers the internal and external forces, on the longline fishing gears, in their mainline depth calculations at equilibrium condition. The Korean displacement analysis is a perfect alternative method to analyzing fishing gears that are at an equilibrium state. In the past, fishing gear scientist relied a lot on the catenary curve principles to analyze the behavior of fishing gears at equilibrium state. Advancement in technology has now allowed fishing gear scientist to use the SimuLine computer software for more accurate and reliable results.

The mainline depth data, shown in Table 12, tells us that the Pythagorean Theorem equation was not applicable for the analysis of longline fishing gears. The result in Table 14, gives the calculated shortening ratios used in the current research and it again tells us that very high shortening ratios were used to produce the longline mainline depth data from the Pythagorean Theorem equation. At high shortening ratios, the speed of vessels and the speed of the line setter for a longline fishing vessel are assumed to be very close values and create shallow mainline and hook depths.

The difference between the computer based simulated longline hook depth, at a controlled ocean current, and the observed field research longline hook depth was very high.

Oceanic conditions play a vital role in determining the effectiveness of the available fishing gear modeling systems. The various fishing ground have unique oceanic conditions and requires fishing gear scientists to continuously develop specific gear models for different parts of the world's ocean.

The Offshore fishing industry in Fiji will benefit a lot with the availability of the SimuLine computer software with the Ministry of the Fisheries. The SimuLine computer software will help developing countries like Fiji to design accurate and reliable fishing gears for the present offshore fishing industry. Other advantages include:

i. Sustainable usage of the tuna resources with the Fiji EEZ.
ii. Lower the destructive nature of some offshore fishing gears from harvesting protected marine fish species and by-catch fish species.
iii. Improve investor confidence to invest in the offshore industry in Fiji and other pacific island countries.
iv. Create employment for low-skilled members of the public.
v. The computer-based simulation software's can also model other types of offshore fishing methods like purse seining, cage culture and trawling.
vi. Accurate and reliable decisions for the development of the offshore fisheries industry in Fiji and other pacific island countries.

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