Akua: Reinvention of Nature

A Reform of Economy, Environment and Society

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I. CONTENTS

II. EXECUTIVE SUMMARY

Our purpose in redesigning Akua island is to create a sustainable, resilient environment with a ripe economy for citizens and visitors alike. In accomplishing our vision in the 2017 Coastal Act, we have three core goals.

Firstly, we have defined our design around creating a sustainable community for the island residents. Island communities face issues sustaining its youth demographic, with a large proportion of young people seeking to move to larger cities to pursue a more urban lifestyle (Leonie Huddy, 2016). To combat this, we plan to improve infrastructure and construct a healthy economy on Akua with many viable jobs.

Our second goal is to conserve the coastline integrity. We have the responsibility to preserve Akua's natural heritage and to showcase it to visitors for generations to come. Its natural allure will be an ideal destination for people to enjoy the untainted landscape of Akua. The tourism industry will play a central role in Akua's economy, bringing jobs and stability to its citizens.

This brings us to our third goal in protecting Akua from the risk of the natural hazards, especially storm surges, which pose a catastrophic threat to the island community and Government budget of Akua.

We believed that our proposed allocation below satisfies the above three goals. This report will give a full explanation our rationale behind this decision.

<table>
<tr><th>Categories</th><th>Zones</th><th colspan="2">Distribution</th></tr>
<tr><td>Conservation</td><td>14-18</td><td>25%</td><td rowspan="2">35%</td></tr>
<tr><td>Recreation</td><td>6 & 9</td><td>10%</td></tr>
<tr><td>Agriculture</td><td>4 & 5</td><td>10%</td><td rowspan="4">65%</td></tr>
<tr><td>Fishing</td><td>7,8,11,20</td><td>20%</td></tr>
<tr><td>Private Housing</td><td>1,2,10,12,19</td><td>25%</td></tr>
<tr><td>Other</td><td>3,13</td><td>10%</td></tr>
</table>

II. STRATEGIC APPROACH

The complexity of applying quantitative models in zone allocation may result in obtaining a solution that are mathematically correct, but physically not desirable. Therefore, human judgement has been a major drive of our strategic approach. In short, our strategy consists of 3 components:

A. **Observation**
B. **Initial Allocation**
C. **Utility Maximization**

A. Observation

First, we identified the relevant zone attributes for each of the six functions:

Table 1

Functions	Duck[1]	Organic[2]	Snapper[3]	Coastline[4]	Wetland[5]	Grassland[6]	Forest[7]	Altitude[8]
Conservation	*				*			
Recreation				*		*	*	*
Agriculture		*				*		
Fishing			*	*				
Private Housing				*		*		*
Other								

[1] Akua Duck population
[2] Average amount of Soil Organic Matter measured in grassland soil as of December 2016 (% organic matter per hectare furrow slice*)
[3] Snapper Exploitation Rate (% of total fish removed by fishing over the past year)
[4] Coastline Length (km)
[5] Wetland Surface Area (Flat Area)
[6] Grassland Surface Area (Flat Area)
[7] Forest Surface Area (% of zone area)
[8] Average altitude measurement 100m inland from December 2016 Mean Sea Level (m)

We analysed each zone individually by looking at its attributes, and ranking their potential. Numerical results can be found in Appendix A.

B. Initial Allocation

We make our initial allocation based on zones that have distinct benefits. In total, there are 12 zones with conditions that are ideal for 1-2 specific functions. These are *Zones 1-5, 7, 13 & 15-18*.

We use Rate Comparison to visualize the trade-off and 5-year Projections of Tides to identity risky zones. Modelling details and the result will be discussed in Section III and V.

C. UTILITY MAXIMIZATION

The remaining 8 zones cannot be judged by general reasoning alone due to the high volume of possible combinations and no clear advantageous characteristic. A model that maximizes the use of remaining resources is needed here. We decided to use Excel Solver to perform this analysis. A unit free coefficient (or index) was introduced in this model for a direct and fair comparison. We designed a Utility Model to generate these coefficients.

Solver eventually generated a combination of zones that maximizes our utility functions designed for each attribute. The result provided us with the zone allocation for the required 8 zones that were left unresolved from our previous steps. Modelling details and the result will be discussed in Section III and V.

III. DATA MODELLING

A. Regression Modelling (Risk Level Projection)

We used linear regression as our model for tide data. To consider seasonal and anomalous fluctuations from storm surges, we have used a 99% upper prediction interval. This upper bound would provide a benchmark for acceptable rises in mean sea levels for the next 5 years.

Since we have no data of sea levels during high tides and storm surges, we used the Pacific Ocean as a basis. These islands typically see a mean amplitude of 0.3-1m in high tide and up to 2m for storm surges (figure 2,3,4, Appendix D). Hence we assume altitudes exceeding our upper bound by more than 3m have low risk.

In other words, we rejected zones to be used as recreation or private housing if:

Altitude – 99% upper bound sea level (extreme seasonal fluctuations) – 3m (extreme storm tides) < 0

From our analysis, we concluded zone 4, 5, 7, 8, 14, 15, 16, and 18 are at risk of high sea levels, hence we do not consider these zones for recreation or private housing.

B. Rate Comparison

Our second model is used to identify comparative advantages and trade offs. To measure performance, we constructed the following *rate equations* intuitively for the five functions based on their relevant factors:

- Conservation rate: χ = Flat wetland area x Duck population

- Recreation rate: ρ = Total of flat grassland and forest area x Coastline length.
- Agriculture rate: α = 1.2 x Flat grassland area x organic matter %
- Fishing rate: λ = 1.2 Coastline length x (1 – Snapper exploitation rate)
- Housing rate: δ = Flat grassland area x Coastline length

These rates help constitute our observation and initial allocation. The rate for other economic development is omitted as it is not dependent on given attributes.

C. Utility Modelling

Table 2: Utility Maximization

Coastal Zone	Allocation[9]	Duck Population[1]	Snapper Rate[3]	Soil Organic[2]	Coastline Length[4]	Wetland Area[5]	Grassland Area[6]	
1	5				12.1		11.184	
: :	: :	: :	: :	: :	: :	: :	: :	
11	4		0.02		8.5			
: :	: :	: :	: :	: :	: :	: :	: :	
18	1	164				4.632		
19	4		0.06		19.3			
20	3			0.092	12.1		19.38504	
Aggregate Value		**723**	**0.067[10]**	**0.097[10]**	**121.8**	**19.5**	**223.2**	
Coefficient[11]		**7**	**8**	**8**	**5**	**5**	**5**	**38[12]**

Source: case_study_v8 (Appendix C)
[9] 1. Conservation; 2.Recreation; 3.Agriculture; 4.Fishing; 5.Private Housing; 6. Other
[10] The average of the rate from 20 zones
[11] Excellent: 9-10; Good: 7-8; Acceptable: 5-6; Poor: 3-4; Very Poor: 1-2
[12] Sum of Coefficient Column

The Regression and Rate Models were used for the allocation of the 12 selected zones. The allocation for the remaining 8 zones was then performed by our utility model.

This model is run by Excel Solver, to process all possible preferred combinations for these 8 zones. The process is run under the constraints of the 2017 Coastal Act zone quota and our priorities, later discussed in Section IV.

The resulting utility of all 20 zones is stored in the **Aggregate Value** row, with 6 values reflecting the amount of resources[(1)-(6)] utilised in the proposed allocation. As such, our goal is to maximise these values of interest.

For a unit free comparison, we use a 10-degree utility coefficient, with a diminishing function as their underlying distribution. We identified the 10 levels of satisfaction by taking the maximum/minimum value, standard deviation, and mean of the data of each of the 6 attributes. The model sums the 6 coefficients, and maximizes the value. Mathematical detail of the individual utility functions is mentioned in Section II and Appendix B.

IV. DATA LIMITATIONS

A. Tide Data

A significant limitation is the incomplete nature of tidal data for a sizeable amount of zones: notably zones 7, 8, 9, 11, 12 and 18. This affects the accuracy of our regression model, as a small sample size will lower the significance of prediction. We need to assume that sea level trend will continue at the same rate in the near future (5 years). The rationale behind using a linear function on the average sea level is supported by slow and steady rise in the global average sea levels for the past centuries (Figure 1, Appendix D) due to melting icebergs.

Another crucial limitation is only having discrete data in monthly mean sea levels. Mean sea level is not a significant risk factor in determining the risk of flood because it gives no information about high tide sea levels (as high and low tide levels are averaged), evens out storm surge effects, and the systematic average sea levels increase only by 2.8 to 3.6 millimetres per year (barely 20mm in 5 years). This has potential repercussions of inaccurate modelling and a misjudgement of risk for relevant zones. To improve upon tide measurements, satellite data or ultrasonic sensors can be used for higher accuracy.

B. Scope of Data

Additional information can help us make a more informed decision and more accuracy in performance rates. These include:

- **Climate of Akua and the frequency of natural hazards;**

  They can provide a more holistic picture for tourism opportunity and natural hazard protection.

- **Topography, Demographics and Population Density of Akua**

  They can have affect our decision in allocating private housing zones more appropriately.

- **Options for other economic development;**

Other useful information includes the size and details of government budget; what disaster plans are in place; disaster risk transfer like insurance (Oliver Mahul, 2015).

C. Utility Modelling

The limited amount of provided information hinders the power of the Utility Model. When designing the model, residents' satisfaction on different tiers of the 6 attributes is needed such that it can accurately describe the trade-offs.

For instance, would conserving 300 ducks be sustainable or are 600 ducks twice as beneficial. This additional information helps build utility functions that match the characteristics of the island.

V. DECISION RATIONALE & TRADE OFFS

Based on our purpose and core goals, we carried out our decision process with the following criteria in mind:

- Allocate zones to maximise overall benefit to Akua citizens
- We have the responsibility to preserve the majority of Akuan nature
- Allocate zones for long-term sustainability

Our allocation of the 20 zones can be divided into two parts. First, we take an overview of all the zones by judging their performance in each function with regard to their rates (Table 3). We rank their rates, and generate a graph for comparison (Graph 1).

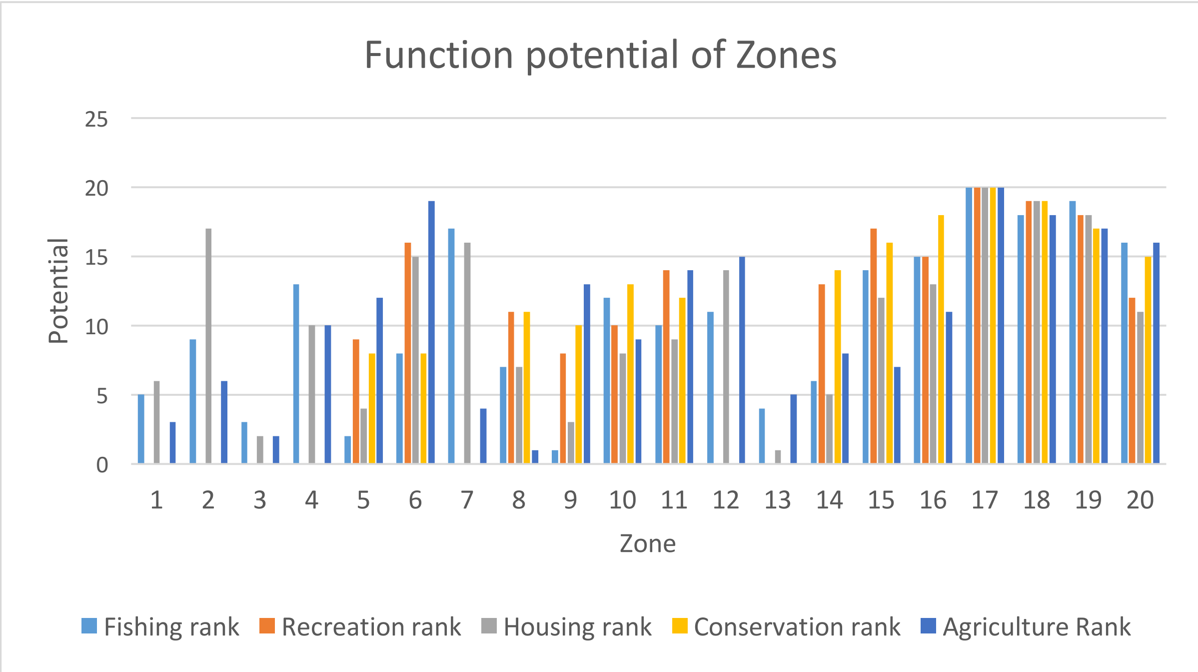
Zone	Fishing rank	Recreation rank	Housing rank	Conservation rank	Agriculture Rank
1	16	-	15	-	18
2	12	-	4	-	15
3	18	-	19	-	19
4	8	-	-	-	11
5	19	-	-	15	9
6	13	8	6	15	2
7	4	-	-	-	17
8	14	-	-	12	20
9	20	-	-	14	8
10	9	16	13	8	12
11	11	11	12	10	7
12	10	-	7	-	6
13	17	-	20	-	16
14	15	-	-	7	13
15	7	-	-	5	14
16	6	-	-	3	10
17	1	1	1	1	1
18	3	-	-	2	3

19	2	5	3	4	4
20	5	14	10	6	5

(a)Gold denotes a top 3 ranking; Green, ranking of 4-8; Blue, ranking of 9-12; No fill, a ranking of 13-20

(b) Recreation and conservation ranks have been omitted for zones without two adjacent zones.

(c) Housing and recreation rates have been omitted for zones with high risk from tides



(i) We denote potential as the rank in descending order e.g. Rank 1 has a potential of 20

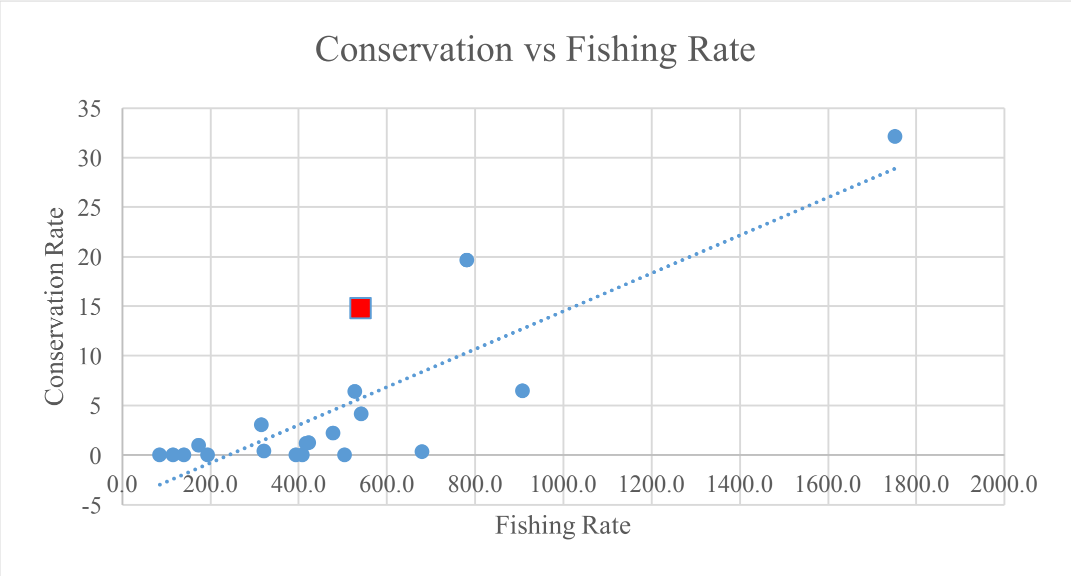
Immediately we notice that there are clear differences in zone performance regarding specific functions. Based on zone potential, we set tiers with S being the highest and E being the lowest:

Tier	Zone				
S	17		18		
A	6		16		19
B	2	7	12	15	20
C	4	9	10	11	14
D	5		8		
E	1		3		13

Using the above data models, we identify zones with clear strengths for particular functions and little or manageable trade offs, as summarised below.

Zone	Preference 1	Rank for Pref 1	Preference 2	Rank for Pref 2	Final Decision
1	Private Housing	15	Other	-	Private Housing
2	Private Housing	4	Fishing	12	Private Housing
3	Other	-	Fishing	18	Other
4	Agriculture	11	Fishing	11	Agriculture
5	Agriculture	9	Fishing	19	Agriculture
7	Fishing	4	Agriculture	17	Fishing
8	Fishing	14	Agriculture	20	Fishing
13	Other	-	Fishing	17	Other
15	Conservation	5	Fishing	7	Conservation
16	Conservation	3	Fishing	6	Conservation
17	Conservation	1	*Any Functions*	1	Conservation
18	Conservation	2	Agriculture	3	Conservation

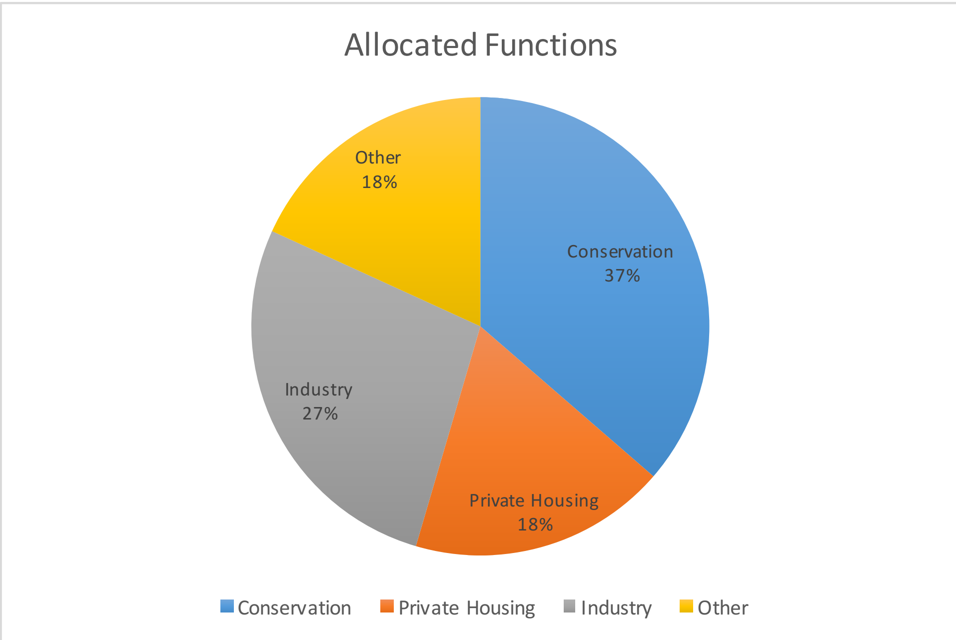
A priority in allocation was conservation, as it had few viable zones, 8, amongst the 20. Our controversial decision here would be the allocation of Zone 17 for conservation, as it has the most significant opportunity cost being the prize zone for all the functions. Hence any allocation for Zone 17 will always carry major trade offs. We prioritised the huge population of ducks (1/3 of the Akua duck population) and the expansive wetlands area. We concluded that the zone was too precious for the Akua environment, and decisions to transform this area into recreation or industry purposes was not responsible. A similar argument can be made for Zones 16 & 18. Below, we compare the first preference and best alternative for Zone 16 (red square), noticing that it has a significant comparative advantage for conservation compared to the general trend.



Hence allocating it as conservation reduces opportunity cost and maximises zone utility. Our priority for conservation will likely be met with conflict from industry representatives. Ultimately our decision is due to our responsibility for the sustainability of Akuan environment. We aim for long-term sustainability, as although higher industry activity would be beneficial for growth it would cause a greater burden on the environment, suggesting future repercussions for Akua.

The rest of the selected zones had compelling advantages and no significant trade offs. Hence, we allocated them based on initial observation and the rank table. When considering alternatives for our selection, they have much lower rate rankings and logically the utility provided would not match our initial selection. Hence we can confidently justify our allocation of these 12 zones.

After this initial allocation, our result is a balance of industry, resident housing, conservation zones, and our two 'other', the lowest potential zones which provide limited utility.



At the moment we are on track with our criteria: we have maximised utility for the Akua economy from our selected industry zones, for society from private housing, carried out our responsibility in preserving Akuan environment, and have minimised trade offs through our two 'other' allocations and favourable allocation thus far.

The second part of our allocation consists of using our utility model to measure marginal and aggregate benefits of allocating the rest of the 8 zones. We do have preferences with the use of these 8 zones according to our result of Rate Comparison and Risk Level Projection. The following table summarises our preference after consideration by methods similar to the previous parts:

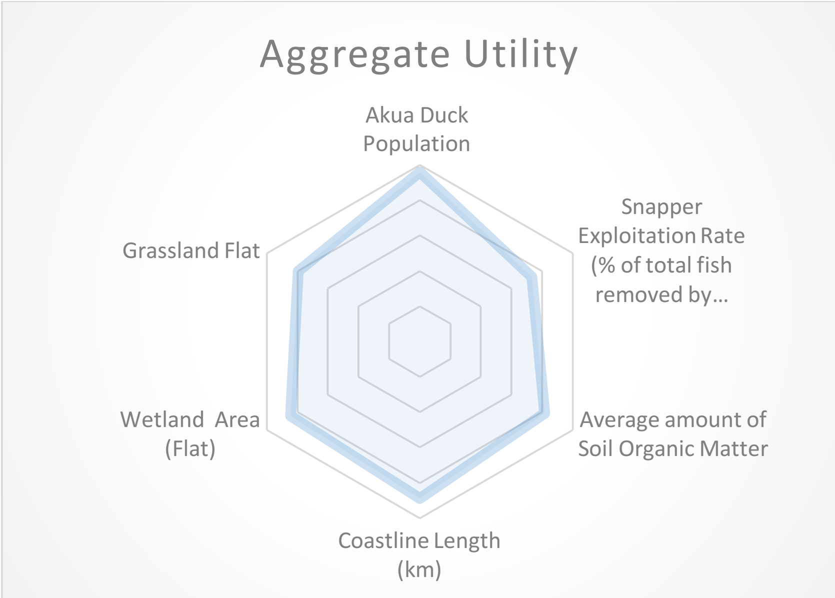
Zone	Conservation	Recreation	Agriculture	Fishing	Private Housing	Final Decision
6		*	*		*	Recreation
9		*			*	Private Housing
10			*	*	*	Private Housing
11		*	*	*	*	Fishing
12			*	*	*	Private Housing
14	*	*		*	*	Conservation
19	*		*	*	*	Private Housing
20		*	*	*	*	Fishing

All constraints and preferences are instructed to the Solver, and the following solution is generated base on our Utility Model:

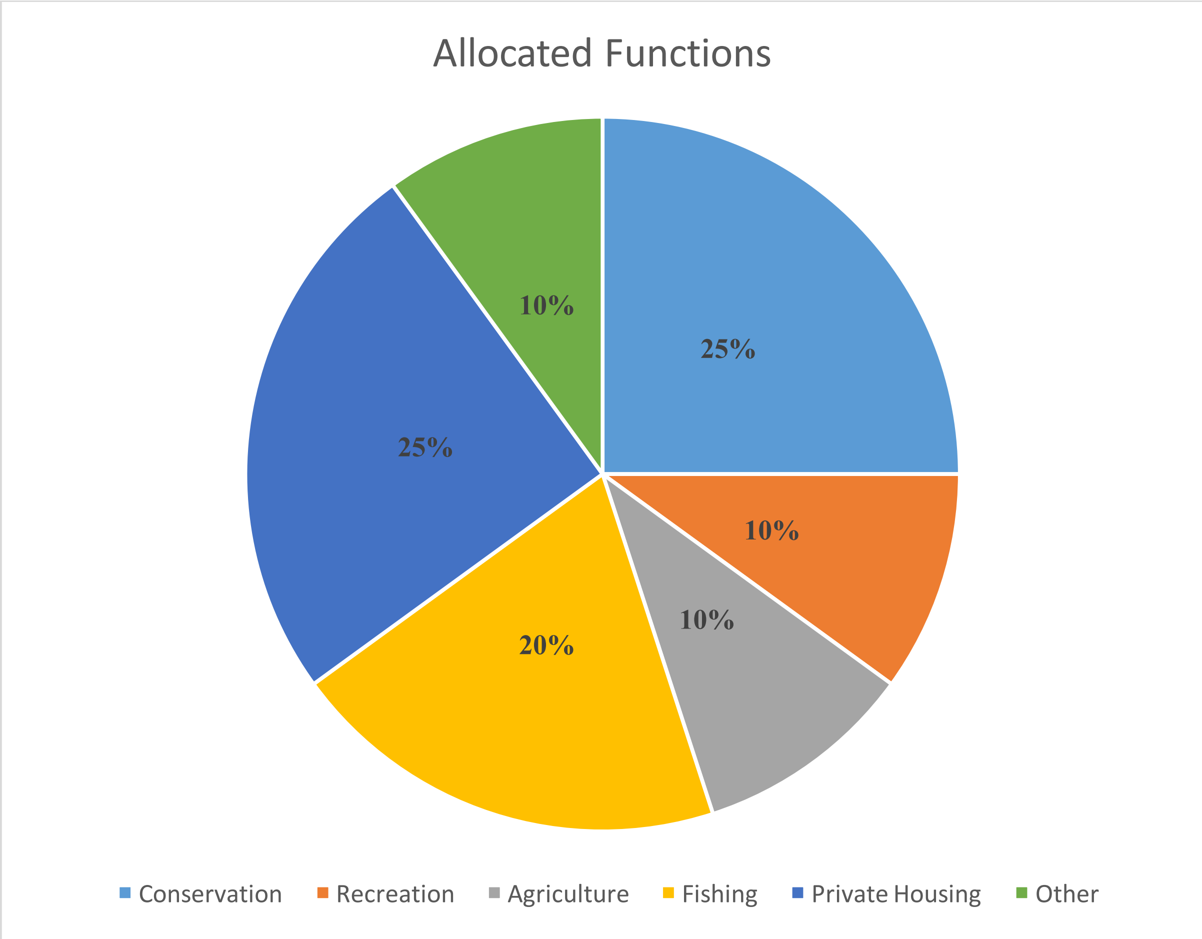
Coastal Zone	Preferences(1)	Duck Population(2)	Snapper Rate(3)	Soil Organic(4)	Coastline Length(5)	Wetland Area(6)	Grassland Area(7)	Utility
1	5				12.1		11	
2	5				21.5		21	
3	6							
4	3			0.102			11	
5	3			0.062			26	
6	2				10.5		32	
7	4		0.22		17.4			
8	4				7.3		20	
9	5				1.9		37	
10	5				10.6		14	
11	4		0.02		8.5			
12	5				9.3		29	
13	6							
14	1	51				2.3		
15	1	64				3.5		
16	1	123				4.0		
17	1	321				5.1		
18	1	164				4.6		
19	5				19.3		24	
20	4		0.05		11.4			
Aggregate Value		**723**	**0.102(8)**	**0.082(8)**	**129.8**	**19.5**	**207**	
Coefficient(9)		**7**	**5**	**6**	**5**	**5**	**4**	**32(10)**

Source: case_study_v6 (Appendix C)
(1) 1. Conservation; 2.Recreation; 3.Agriculture; 4.Fishing; 5.Private Housing; 6. Other
(2) Akua Duck Population (number of birds)
(3) Snapper Exploitation Rate (% of total fish removed by fishing over the past year)
(4) Average amount of Soil Organic Matter measured in grassland soil as of December 2016 (% organic matter per hectare furrow slice*)
(5) Coastline Length (km)(6) Wetland Surface Area (Flat)
(7) Grassland Surface Area (Flat)
(8) The average of the rate from 20 zones

(9) Excellent: 9-10; Good: 7-8; Acceptable: 5-6; Poor: 3-4; Very Poor: 1-2
(10) Sum of Coefficient Column



This gives the result of our proposed allocation. It satisfies our goal in maximising utility for the island, although some allocations were brought to our attention. The first is the total of five private housing zones. In our model, private housing provides greater infrastructure and quality of life to citizens, contributing significantly to utility. Also the zones in this allocation by tier are: 1 A, 2 B, 1 C, and 1 E. This is a rational spread suggesting that zone potential has been divided sensibly. The other issue is balancing the utility of environmental and economic zones. It is difficult to hypothesise whether marginal changes between functions will be beneficial, for example, having an additional recreation zone rather than private housing. This is complicated by the variable quota, hence there is no correct, practical solution. Based on our core goals and team judgement, we see conservation zones as essential for the island, they attract tourists, environmental research and preserves natural integrity. Hence we forego greater industry activity for comprehensive conservation of the island. Also we see tourists and Akua citizens as being conscious of natural sustainability, hence our conservation efforts will undoubtedly draw support from the wider community.



We have checked all the allocation one by one again, and confirmed that they are feasible and practical. This concludes the decision making process.

VI. CONCLUSION & CHALLENGES

Finding a balance between the conflicting interests of industry stakeholders and environmentalists was a challenge, as there is no specific benchmark for either requirement which leaves us to define it. We suggest that the Coastal Commission or city government to conduct a community vote or survey of the residents to obtain a general consensus. The World Bank is a prime example in their actions of rebuilding Pacific islands, transforming opportunities in the islands for tourism and coastal industries to bolster the economy and help sustain the island community, which became our model for our reconstruction of Akua (The World Bank, 2017).

Ultimately, our proposed allocation of the zones achieves our purpose. We have maximised the utility obtained from the zones to the economic and social benefit for Akua citizens, conserved the natural heritage of Akua based on high potential conservation zones, and planned careful allocation of zones for the risk of natural hazards for long-term sustainability.

IX. APPENDIX

A. Zones Analysis

Zone Attributes Table summary.docx

B. Utility Functions

utility_graph_v2.docx

C. Analysis

case_study_v8.xlsx

D. Regression Modelling (Tide Level)

Appendix D excel.xlsm

APPENDIX-D.docx

E. Reference / Sources

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