Habitat Equivalency Analysis of the Kilo Wharf Extension Project in Apra Harbor, Guam

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1 Introduction

This report documents the ***habitat equivalency analysis*** (HEA) of the Kilo Wharf project in Apra Harbor, Guam. HEA can be used to scale, or to determine the appropriate quantity of, the compensatory mitigation measures that will be recommended for the project (King and Adler, 1991). This HEA addresses the two alternatives that are currently under consideration: Western Extension and West-East Extension.

Compensatory mitigation is intended to replace the ***ecological functions*** that are lost as a result of unavoidable impacts to resources affected by the project. Ecological functions refer to the functions performed by a resource for the benefit of other resources or the public, such as the provision of food and refuge for fish populations. The ***baseline*** for quantifying lost ecological functions is the full complement of functions that would have been provided absent project implementation. Lost ecological functions are quantified as the reduction in the provision of functions below this baseline. Compensatory mitigation is recommended as a means to provide a replacement for these lost ecological functions.

It is important to scale compensatory mitigation to be commensurate with the type, level, and duration of lost functions.[1] The amount of compensatory mitigation needed to replace lost functions depends, in part, on the ability of the affected resources to return to their baseline conditions. Factors relevant in that regard include the quantity of affected resources and how fast and how completely they return to their baseline conditions. The amount of compensatory mitigation also depends on the ability of the selected compensatory mitigation measures to replace lost functions. Relevant factors for replacement include how fast the compensatory mitigation measures become fully functional and the relative degree to which they provide additional ecological functions.

This report provides a brief description of the HEA methodology followed by a description of the analytic inputs and results for the Kilo Wharf project. Details of this HEA are presented in Appendix 1 of this report for the Western Extension and West-East Extension alternatives. Appendix 2 presents a mathematical derivation and interpretation of the HEA solution.

2 Description of Habitat Equivalency Analysis

King and Adler (1991) first described habitat equivalency analysis as a methodology for scaling compensatory mitigation under Section 404 of the Clean Water Act. A more recent description of the methodology can be found in Allen, Chapman, and Lane (2005). Briefly, HEA scales compensatory mitigation so that the total quantity of ecological

[1] A memorandum of agreement between the two Federal agencies that administer the Clean Water Act Section 404 program (US Department of the Army and US Environmental Protection Agency, 1990) states that “The determination of what level of mitigation constitutes ‘appropriate’ mitigation is based solely on the values and functions of the aquatic resource that will be impacted.” Further, where “practicable,” the Army Corps of Engineers “will strive to achieve a goal of no overall net loss of values and functions.”

functions it provides is sufficient to offset the total quantity of lost ecological functions resulting from the project impacts. When quantifying ecological functions, it is important to note that they have a temporal dimension as well as a geographic dimension (e.g., a given area of coral habitat provides beneficial functions over a period of time). Therefore, ecological functions are quantified in HEA in units of measure such as ***acre-years***. An acre-year refers to all the ecological functions provided by one acre of habitat for one year. For example, 100 acre-years of functions might be provided by a 5-acre habitat over a period of 20 years, or by a 10-acre habitat over a 10-year period.[2] This characterization captures not only the important aspect of the physical size of a resource, but also the fact that the period of time it continues to function is important as well.

This measure of ecological functions is obviously specific to habitat since different habitats provide different functions. Therefore, it is important to select compensatory mitigation measures that provide replacement functions that are comparable to the lost functions (i.e., in-kind replacement). If that is not possible, some meaningful adjustment must be made to equate the replacement functions to lost functions.

Another important consideration is time preference. In general, people prefer present resource uses over future uses for a variety of reasons (such as uncertainty and impatience). This time preference is important when considering how to balance lost and replacement functions that occur at different times since their tradeoffs vary through time. Therefore, the quantities of ecological functions occurring at different times are not valued on an equivalent basis and must be adjusted before they can be compared in a meaningful way. This adjustment process, known as ***discounting***, permits one to examine quantities occurring at different times on a comparable basis. The adjustment involves decreasing future quantities, and increasing past quantities, each year by a proportional amount known as the discount rate. Discounting in this context is analogous to a bank's calculation of compound interest for a deposit or loan. The common time period to which all lost and replacement ecological functions are discounted for sake of comparison is known as the present time period. For this analysis, the present time period is the year in which the HEA was conducted (2007).

Through this process of quantifying and discounting ecological functions, HEA takes into account losses and gains that occur over different timeframes to determine a scale of compensatory mitigation that is commensurate with the type, level, and duration of lost functions. Because HEA accounts for all these important aspects, different compensatory mitigation projects will generally have different scales. For example, a compensatory mitigation project that becomes fully functional in 5 years will have a smaller indicated scale than one that requires 10 years to become fully functional. Therefore, it is important that the compensatory mitigation projects selected for analysis be chosen carefully. HEA is not used to select compensatory mitigation projects, only to determine their scale.

HEA has also been used in other policy contexts involving the loss of ecological functions. For example, it is widely used in natural resource damage assessments

[2] This example abstracts from the issues of discounting, as discussed below.

conducted under the Oil Pollution Act of 1990 (33 U.S.C. 2701 *et seq.*) and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (42 U.S.C. 9601 *et seq.*).[3] It has also been used to quantify consequences in ecological risk assessment (Linder et al., 2005).

3 Analytic Inputs for the Western Extension Alternative

The following analytic inputs were used in the habitat equivalency analysis for the Western Extension alternative. Detailed HEA calculations for this alternative are presented in Appendix 1 of this report.

3.1 Project Impacts

Foster et al. (2006) detail the expected impacts associated with the Western Extension alternative. For purposes of this analysis, these impacts have been grouped by habitat (i.e., reef flat/crest and reef slope) and by impact (i.e., dredge/fill, anchor/wire, sedimentation, and suspended sediments). Project implementation and the resulting onset of lost functions are assumed to begin in 2008. The specific analytic inputs that quantify lost functions for these habitats are summarized in this section for the Western Extension alternative. Except where noted, all HEA inputs describing project impacts are referenced in Foster et al. (2006).

- Discounting inputs
    - Annual discount rate: 3.0% (Peacock, 1995)
    - Present year: 2007
- Lost functions inputs
    - Reef Flat/Crest - Dredge/Fill
        - Affected habitat: 2.066 acres, including dredge (0.02 acres), dredge buffer (0.2 acres), fill (1.77 acres), existing mooring (0.03 acres), existing mooring buffer (0.016 acres), and new mooring (0.03 acres) (Foster pers. com., 2/1/07)
        - Lost functions time path: 100% in 2008 and into perpetuity (Foster pers. com., 7/11/06)
    - Reef Flat/Crest - Anchor/Wire
        - Affected habitat: 0.8 acres (Foster pers. com., 2/1/07)
        - Lost functions time path
            - 100% in 2008 (Foster pers. com., 7/11/06)
            - 0% in 2108

[3] For example, see Unsworth and Petersen (1995) and National Park Service (2003).

      - Linear recovery time path between 2008 and 2108 (Foster pers. com., 7/11/06)

- Reef Flat/Crest - Sedimentation
  - Affected habitat: 1.34 acres
  - Lost functions time path
    - 20% in 2008 through 2010 (Foster pers. com., 7/11/06)
    - 0% in 2018
    - Linear recovery time path between 2010 and 2018 (Foster pers. com., 7/11/06)

- Reef Flat/Crest - Suspended Sediments
  - Affected habitat: 13.37 acres, including reef flat/slope
  - Lost functions time path
    - 5% in 2008 through 2010 (Foster pers. com., 7/11/06)
    - 0% in 2011

- Reef Slope - Dredge/Fill
  - Affected habitat: 0.47 acres, including dredge (0.04 acres), dredge buffer (0.36 acres), and fill (0.07 acres) (Foster pers. com., 2/1/07)
  - Lost functions time path: 100% in 2008 and into perpetuity (Foster pers. com., 7/11/06)

- Reef Slope - Anchor/Wire
  - Affected habitat: 0.59 acres (Foster pers. com., 2/1/07)
  - Lost functions time path
    - 100% in 2008 (Foster pers. com., 7/11/06)
    - 0% in 2108
    - Linear recovery time path between 2008 and 2108 (Foster pers. com., 7/11/06)

These inputs indicate the levels of lost functions presented in Table 1.

Table 1
Lost Functions at Kilo Wharf:
Western Extension Alternative

Habitat	Acre-Years[a]
Reef Flat/Crest	90.5
Reef Slope	29.1

[a]Detailed calculations are presented in Appendix 1 of this report.

3.2 Compensatory Mitigation

The recommended compensatory mitigation measures involve controlling upland sources of sediment deposition into Sella Bay so that coral communities and associated habitats adversely affected by terrigenous sediment can naturally re-establish themselves (Foster pers. com., 7/11/06). This biological response within the bay defines the replacement functions that are intended to offset losses at the Kilo Wharf project site. Replacement functions are quantified in HEA as a proportional equivalence to the functions lost from project impacts. For example, replacement functions that are fully equivalent to those lost from project impacts would be quantified as 100%.[4] This proportional equivalence is known as ***relative productivity***.

No biological response is expected within Sella Bay during the 10-year period immediately following implementation of compensatory mitigation. After that period, coral communities and associated habitats within the bay are expected to achieve their maximum relative productivity incrementally over a 100-year period, and to maintain that maximum level into perpetuity (Foster pers. com., 7/11/06). These time periods reflect the maximum age of relic corals observed in the bay, and allow time for the natural removal of sediment and the subsequent recruitment of coral and other biota. Implementation of compensatory mitigation was assumed to begin in 2008.

The measure of relative productivity used in this analysis was based on the diameters of living and nonliving coral colonies (Foster pers. com., 9/27/06). Coral, as the predominant structural and biological feature of the affected habitats, was considered an appropriate focus of this measure. Diameter was considered an appropriate quantitative basis since it is a comparable measure between the different physical forms of coral, and generally indicates habitat cover. Inclusion of nonliving corals in this measure was also considered to capture the potential for mitigation in Sella Bay. This measure is also readily available in terms of the time and other resources required for data collection and analysis.

Surveys were conducted in Sella Bay and at the Kilo Wharf project site to measure, among other things, the number of corals per square meter and their distribution by diameter size class (Brown and Kolinski, 2006; Foster et al., 2006). The average diameter per square meter of all observed corals was calculated by applying the number of corals per square meter to their diameter size class distribution, and then averaging within the different habitats (reef flat/crest and reef slope). Details of this calculation are presented in Appendix 1.

A comparison of the average diameters per square meter in Sella Bay and at the Kilo Wharf project site was used to determine the maximum relative productivity of compensatory mitigation. Maximum relative productivity quantifies the replacement functions provided after compensatory mitigation becomes fully functional. As described above, compensatory mitigation is expected to become fully functional 110 years after

[4] Proportions are expressed in this report as percentages for presentation purposes only.

implementation in 2008. Therefore, relative productivity was varied linearly in this analysis from 0% in 2018 (allowing an initial 10-year period with no biological response within the bay) to its maximum level in 2118. The maximum level of relative productivity was assumed to continue past 2118 into perpetuity.

These levels of relative productivity were then discounted to the present time period (2007) at 3% per year to determine the total present value of relative productivity. The total present value of relative productivity expressed as a proportion is interpreted in HEA as the total number of acre-years of replacement functions provided by each acre of mitigation (within the bay) throughout the life time of the mitigation measures (see Appendix 2 for details).

Finally, the total present value of relative productivity was adjusted to reflect uncertainty in the future success of the recommended compensatory mitigation measures. Since the probability of mitigation success has not been quantified for these measures, a sensitivity analysis was conducted by assuming three levels of mitigation success: 100 percent, 75 percent, and 50 percent. These calculations are detailed in Appendix 1 and summarized in Table 2. The mathematical derivation and interpretation of the HEA solution under conditions of mitigation uncertainty are presented in Appendix 2.

Table 2
Relative Productivity of Compensatory Mitigation in Sella Bay

Alternative/Habitat	Maximum Relative Productivity	Total Present Value of Relative Productivity[a]	Expected Replacement Functions per Acre of Mitigation for Given Levels of Mitigation Success[b]
Western Extension			
Reef Flat/Crest	95.7%	750.2%	7.502 acre-years (100% success) 5.626 acre-years (75% success) 3.751 acre-years (50% success)
Reef Slope	384.7%	3,014.8%	30.148 acre-years (100% success) 22.611 acre-years (75% success) 15.074 acre-years (50% success)
West-East Extension			
Reef Flat/Crest	105.9%	830.2%	8.302 acre-years (100% success) 6.226 acre-years (75% success) 4.151 acre-years (50% success)
Reef Slope	203.8%	1,597.6%	15.976 acre-years (100% success) 11.982 acre-years (75% success) 7.988 acre-years (50% success)

[a]Discounted to 2007 at 3% per year.
[b]Given level of mitigation success applied to the total present value of relative productivity expressed as a proportion.

The levels of replacement functions per acre of mitigation presented in Table 2 were then applied to the number of acres of the different habitats in Sella Bay to determine the total level of expected replacement functions in the bay. These totals are presented in Table 3.

Table 3
Total Expected Replacement Functions in Sella Bay

Alternative/Habitat	Acres Within Sella Bay[a]	Total Expected Replacement Functions for Given Levels of Mitigation Success[b]
Western Extension		
Reef Flat/Crest	7.5	56.3 acre-years (100% success) 42.2 acre-years (75% success) 28.1 acre-years (50% success)
Reef Slope	10.7	322.6 acre-years (100% success) 241.9 acre-years (75% success) 161.3 acre-years (50% success)
West-East Extension		
Reef Flat/Crest	7.5	62.3 acre-years (100% success) 46.7 acre-years (75% success) 31.1 acre-years (50% success)
Reef Slope	10.7	170.9 acre-years (100% success) 128.2 acre-years (75% success) 85.5 acre-years (50% success)

[a]Foster pers. com. (9/5/06).
[b]Calculated as the acres within Sella Bay for each habitat multiplied by the respective expected replacement functions per acre of mitigation from Table 2.

4 Analytic Inputs for the West-East Extension Alternative

The following analytic inputs were used in the habitat equivalency analysis for the West-East Extension alternative. Detailed HEA calculations for this alternative are presented in Appendix 1 of this report.

4.1 Project Impacts

Foster et al. (2006) detail the expected impacts associated with the West-East Extension alternative. Similar to the Western Extension alternative, the impacts for the West-East Extension alternative have been grouped by habitat (i.e., reef flat/crest and reef slope) and by impact (i.e., dredge/fill, anchor/wire, sedimentation, and suspended sediments). Project implementation and the resulting onset of lost functions are assumed to begin in 2008. The specific analytic inputs that quantify lost functions for these habitats are summarized in this section for the West-East Extension alternative. Except where noted, all HEA inputs describing project impacts are referenced in Foster et al. (2006).

- Discounting inputs
    - Annual discount rate: 3.0% (Peacock, 1995)
    - Present year: 2007

- Lost functions inputs
    - Reef Flat/Crest - Dredge/Fill
        - Affected habitat: 2.466 acres, including dredge (0.04 acres), dredge buffer (0.35 acres), fill (2.0 acres), existing mooring 0.03 acres), existing mooring buffer (0.016 acres), and new mooring (0.03 acres) (Foster pers. com., 2/1/07)
        - Lost functions time path: 100% in 2008 and into perpetuity (Foster pers. com., 7/11/06)

    - Reef Flat/Crest - Anchor/Wire
        - Affected habitat: 1.43 acres (Foster pers. com., 2/1/07)
        - Lost functions time path
            - 100% in 2008 (Foster pers. com., 7/11/06)
            - 0% in 2108
            - Linear recovery time path between 2008 and 2108 (Foster pers. com., 7/11/06)

    - Reef Flat/Crest - Sedimentation
        - Affected habitat: 1.83 acres
        - Lost functions time path
            - 20% in 2008 through 2010 (Foster pers. com., 7/11/06)
            - 0% in 2018
            - Linear recovery time path between 2010 and 2018 (Foster pers. com., 7/11/06)

    - Reef Flat/Crest - Suspended Sediments
        - Affected habitat: 18.38 acres, including reef flat/slope
        - Lost functions time path
            - 5% in 2008 through 2010 (Foster pers. com., 7/11/06)
            - 0% in 2011[5]

    - Reef Slope - Dredge/Fill
        - Affected habitat: 0.67 acres, including dredge (0.08 acres), dredge buffer (0.54 acres), and fill (0.05 acres) (Foster pers. com., 2/1/07)
        - Lost functions time path: 100% in 2008 and into perpetuity (Foster pers. com., 7/11/06)

[5] Foster et al. (2006) indicate a 38-month impact duration. However, since time in this HEA is denominated by whole years, this impact duration was rounded down to the nearest whole year.

- Reef Slope - Anchor/Wire
  - Affected habitat: 1.16 acres (Foster pers. com., 2/1/07)
  - Lost functions time path
    - 100% in 2008 (Foster pers. com., 7/11/06)
    - 0% in 2108
    - Linear recovery time path between 2008 and 2108 (Foster pers. com., 7/11/06)

These inputs indicate the levels of lost functions presented in Table 4.

Table 4
Lost Functions at Kilo Wharf:
West-East Extension Alternative

Habitat	Acre-Years[a]
Reef Flat/Crest	119.5
Reef Slope	48.8

[a]Detailed calculations are presented in Appendix 1 of this report.

4.2 Compensatory Mitigation

The same relative productivity inputs presented in section 3.2 for the Western Extension alternative were used for the West-East Extension alternative.

5 Summary of Results

Given the recommended compensatory mitigation measures, scaling involves comparing the acre-years of lost functions at the Kilo Wharf project site with the acre-years of expected replacement functions provided by compensatory mitigation in Sella Bay. To place that comparison in the context of the affected habitats at Kilo Wharf and the habitats available for mitigation at Sella Bay, the acreages of the respective habitats are presented in Table 5. The intent of comparing the acre-years of lost functions to the acre-years of replacement functions is to determine whether the recommended compensatory mitigation measures are sufficient to offset the lost functions resulting from project impacts. That comparison is presented in Table 6 for all alternatives considered.

The following general conclusions are drawn from the comparison of lost and replacement functions in Table 6.

- The indicated lost functions under the West-East Extension alternative are ***greater*** than those under the Western Extension alternative (between 32 and 68 percent greater, depending on the affected habitat). This point is illustrated in Figure 1.

- Under both alternatives, the indicated expected replacement functions for the reef flat/crest habitat are ***less*** than the associated lost functions (between 38 and 74 percent less, depending on the alternative and the probability of mitigation success). This point is illustrated in Figure 2.
- Under both alternatives, the indicated expected replacement functions for the reef slope habitat are ***greater*** than the associated lost functions (between 75 and 1,009 percent greater, depending on the alternative and the probability of mitigation success). This point is illustrated in Figure 3.

Table 5
Affected Habitats at the Kilo Wharf Project Site and Habitats Available for Mitigation at Sella Bay

Alternative/Habitat	Kilo Wharf Project Site	Sella Bay
Western Extension		
Reef Flat/Crest	17.576 acres	7.5 acres
Reef Slope	1.06 acres	10.7 acres
West-East Extension		
Reef Flat/Crest	24.106 acres	7.5 acres
Reef Slope	1.83 acres	10.7 acres

Note: Acreages listed for the kilo Wharf project site account for all impacts, including dredge/fill, anchor/wire, sedimentation, and suspended sediments. These acreages do not account for the degree or time period of impacts.

Table 6
Comparison of Lost and Expected Replacement Functions for the Kilo Wharf Project

Alternative/Habitat	Acre-Years of Lost Functions at the Kilo Wharf Project Site	Acre-Years of Expected Replacement Functions at Sella Bay for Given Levels of Mitigation Success
Western Extension		
Reef Flat/Crest	90.5 acre-years	56.3 acre-years (100% success) 42.2 acre-years (75% success) 28.1 acre-years (50% success)
Reef Slope	29.1 acre-years	322.6 acre-years (100% success) 241.9 acre-years (75% success) 161.3 acre-years (50% success)
West-East Extension		
Reef Flat/Crest	119.5 acre-years	62.3 acre-years (100% success) 46.7 acre-years (75% success) 31.1 acre-years (50% success)
Reef Slope	48.8 acre-years	170.9 acre-years (100% success) 128.2 acre-years (75% success) 85.5 acre-years (50% success)

Figure 1
Lost Functions at Kilo Wharf

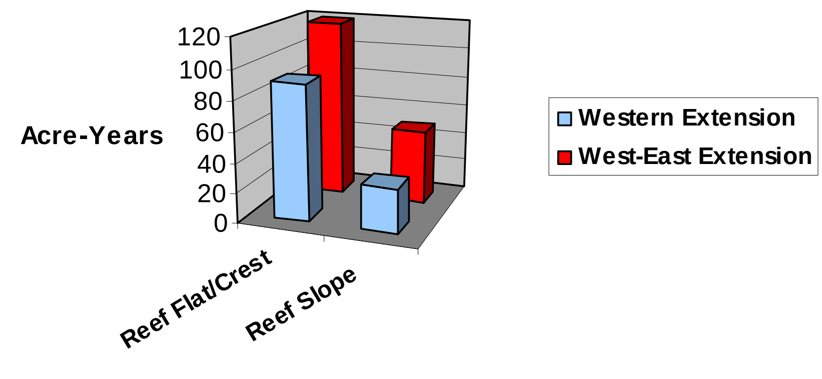


Figure 2
Lost and Expected Replacement Functions: Reef Flat/Crest

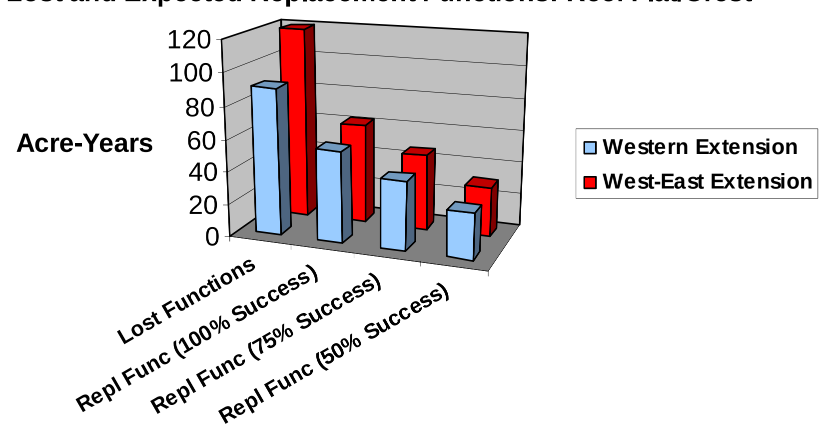
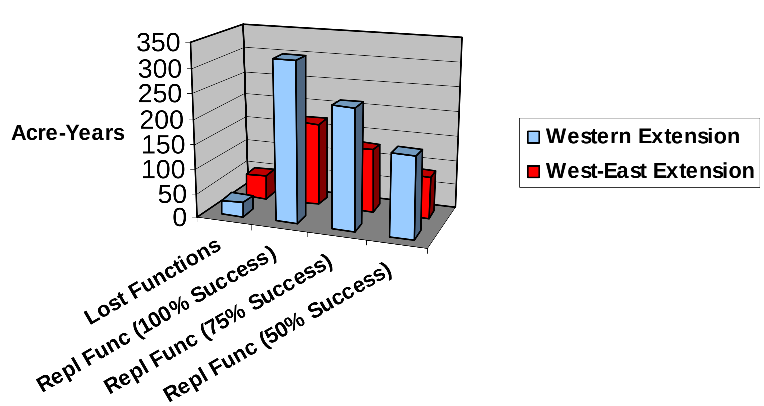


Figure 3
Lost and Replacement Functions: Reef Slope



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Appendix 1

Detailed Habitat Equivalency Analysis Calculations: Kilo Wharf Project

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Habitat Equivalency Analysis of Kilo Wharf
Summary: All Alternatives

Summary of Lost and Expected Replacement Functions

Alternative/Habitat	Lost Functions at Kilo Wharf (Acre-Years)	Probability of Mitigation Success	Expected Replacement Functions at Sella Bay (Acre-Years)
Western Extension			
Reef Flat/Crest	90.5	100%	56.3
		75%	42.2
		50%	28.1
Reef Slope	29.1	100%	322.6
		75%	241.9
		50%	161.3
West-East Extension			
Reef Flat/Crest	119.5	100%	62.3
		75%	46.7
		50%	31.1
Reef Slope	48.8	100%	170.9
		75%	128.2
		50%	85.5

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Habitat Equivalency Analysis of Kilo Wharf
Lost Functions: Western Extension

Annual Discount Rate: 3.0%

Present Year: 2007

Reef Flat/Crest

Habitat Impact (Acres)
Dredge/Fill: 2.066 (includes dredge, dredge buffer, fill, existing mooring, existing mooring buffer, and new mooring areas)
Anchor/Wire: 0.800
Sedimentation: 1.340
Sup Sediments: 13.370 (includes reef flat/slope)

	<----Habitat Impact----			---->	<----(Acre-Years)----	---->
Year	**Dredge/Fill**	**Anchor/Wire**	**Sedimentation**	**Sup Sediments**	**Current Value**	**Present Value**
2008	100.0%	100.0%	20.0%	5.0%	3.80	3.69
2009	100.0%	99.0%	20.0%	5.0%	3.79	3.58
2010	100.0%	98.0%	20.0%	5.0%	3.79	3.47
2011	100.0%	97.0%	17.5%	0	3.08	2.73
2012	100.0%	96.0%	15.0%		3.04	2.62
2013	100.0%	95.0%	12.5%		2.99	2.51
2014	100.0%	94.0%	10.0%		2.95	2.40
2015	100.0%	93.0%	7.5%		2.91	2.30
2016	100.0%	92.0%	5.0%		2.87	2.20
2017	100.0%	91.0%	2.5%		2.83	2.10
2018	100.0%	90.0%	0.0%		2.79	2.01
2019	100.0%	89.0%			2.78	1.95
2020	100.0%	88.0%			2.77	1.89
2021	100.0%	87.0%			2.76	1.83
2022	100.0%	86.0%			2.75	1.77
2023	100.0%	85.0%			2.75	1.71
2024	100.0%	84.0%			2.74	1.66
2025	100.0%	83.0%			2.73	1.60

2026	100.0%	82.0%	2.72	1.55
2027	100.0%	81.0%	2.71	1.50
2028	100.0%	80.0%	2.71	1.45
2029	100.0%	79.0%	2.70	1.41
2030	100.0%	78.0%	2.69	1.36
2031	100.0%	77.0%	2.68	1.32
2032	100.0%	76.0%	2.67	1.28
2033	100.0%	75.0%	2.67	1.24
2034	100.0%	74.0%	2.66	1.20
2035	100.0%	73.0%	2.65	1.16
2036	100.0%	72.0%	2.64	1.12
2037	100.0%	71.0%	2.63	1.09
2038	100.0%	70.0%	2.63	1.05
2039	100.0%	69.0%	2.62	1.02
2040	100.0%	68.0%	2.61	0.98
2041	100.0%	67.0%	2.60	0.95
2042	100.0%	66.0%	2.59	0.92
2043	100.0%	65.0%	2.59	0.89
2044	100.0%	64.0%	2.58	0.86
2045	100.0%	63.0%	2.57	0.84
2046	100.0%	62.0%	2.56	0.81
2047	100.0%	61.0%	2.55	0.78
2048	100.0%	60.0%	2.55	0.76
2049	100.0%	59.0%	2.54	0.73
2050	100.0%	58.0%	2.53	0.71
2051	100.0%	57.0%	2.52	0.69
2052	100.0%	56.0%	2.51	0.66
2053	100.0%	55.0%	2.51	0.64
2054	100.0%	54.0%	2.50	0.62
2055	100.0%	53.0%	2.49	0.60
2056	100.0%	52.0%	2.48	0.58
2057	100.0%	51.0%	2.47	0.56
2058	100.0%	50.0%	2.47	0.55
2059	100.0%	49.0%	2.46	0.53
2060	100.0%	48.0%	2.45	0.51
2061	100.0%	47.0%	2.44	0.49
2062	100.0%	46.0%	2.43	0.48

2063	100.0%	45.0%	2.43	0.46
2064	100.0%	44.0%	2.42	0.45
2065	100.0%	43.0%	2.41	0.43
2066	100.0%	42.0%	2.40	0.42
2067	100.0%	41.0%	2.39	0.41
2068	100.0%	40.0%	2.39	0.39
2069	100.0%	39.0%	2.38	0.38
2070	100.0%	38.0%	2.37	0.37
2071	100.0%	37.0%	2.36	0.36
2072	100.0%	36.0%	2.35	0.34
2073	100.0%	35.0%	2.35	0.33
2074	100.0%	34.0%	2.34	0.32
2075	100.0%	33.0%	2.33	0.31
2076	100.0%	32.0%	2.32	0.30
2077	100.0%	31.0%	2.31	0.29
2078	100.0%	30.0%	2.31	0.28
2079	100.0%	29.0%	2.30	0.27
2080	100.0%	28.0%	2.29	0.26
2081	100.0%	27.0%	2.28	0.26
2082	100.0%	26.0%	2.27	0.25
2083	100.0%	25.0%	2.27	0.24
2084	100.0%	24.0%	2.26	0.23
2085	100.0%	23.0%	2.25	0.22
2086	100.0%	22.0%	2.24	0.22
2087	100.0%	21.0%	2.23	0.21
2088	100.0%	20.0%	2.23	0.20
2089	100.0%	19.0%	2.22	0.20
2090	100.0%	18.0%	2.21	0.19
2091	100.0%	17.0%	2.20	0.18
2092	100.0%	16.0%	2.19	0.18
2093	100.0%	15.0%	2.19	0.17
2094	100.0%	14.0%	2.18	0.17
2095	100.0%	13.0%	2.17	0.16
2096	100.0%	12.0%	2.16	0.16
2097	100.0%	11.0%	2.15	0.15
2098	100.0%	10.0%	2.15	0.15
2099	100.0%	9.0%	2.14	0.14

2100	100.0%	8.0%	2.13	0.14
2101	100.0%	7.0%	2.12	0.13
2102	100.0%	6.0%	2.11	0.13
2103	100.0%	5.0%	2.11	0.12
2104	100.0%	4.0%	2.10	0.12
2105	100.0%	3.0%	2.09	0.12
2106	100.0%	2.0%	2.08	0.11
2107	100.0%	1.0%	2.07	0.11
2108	100.0%	0.0%	2.07	0.10
Beyond				3.48
Total				90.54

Reef Slope

Habitat Impact (Acres)
Dredge/Fill: 0.470 (includes dredge, dredge buffer, and fill areas)
Anchor/Wire: 0.590

	<-----------Habitat Impact----------->		<-------------(Acre-Years)------------->	
Year	**Dredge/Fill**	**Anchor/Wire**	**Current Value**	**Present Value**
2008	100.0%	100.0%	1.06	1.03
2009	100.0%	99.0%	1.05	0.99
2010	100.0%	98.0%	1.05	0.96
2011	100.0%	97.0%	1.04	0.93
2012	100.0%	96.0%	1.04	0.89
2013	100.0%	95.0%	1.03	0.86
2014	100.0%	94.0%	1.02	0.83
2015	100.0%	93.0%	1.02	0.80
2016	100.0%	92.0%	1.01	0.78
2017	100.0%	91.0%	1.01	0.75
2018	100.0%	90.0%	1.00	0.72
2019	100.0%	89.0%	1.00	0.70
2020	100.0%	88.0%	0.99	0.67
2021	100.0%	87.0%	0.98	0.65
2022	100.0%	86.0%	0.98	0.63
2023	100.0%	85.0%	0.97	0.61

2024	100.0%	84.0%	0.97	0.58
2025	100.0%	83.0%	0.96	0.56
2026	100.0%	82.0%	0.95	0.54
2027	100.0%	81.0%	0.95	0.52
2028	100.0%	80.0%	0.94	0.51
2029	100.0%	79.0%	0.94	0.49
2030	100.0%	78.0%	0.93	0.47
2031	100.0%	77.0%	0.92	0.45
2032	100.0%	76.0%	0.92	0.44
2033	100.0%	75.0%	0.91	0.42
2034	100.0%	74.0%	0.91	0.41
2035	100.0%	73.0%	0.90	0.39
2036	100.0%	72.0%	0.89	0.38
2037	100.0%	71.0%	0.89	0.37
2038	100.0%	70.0%	0.88	0.35
2039	100.0%	69.0%	0.88	0.34
2040	100.0%	68.0%	0.87	0.33
2041	100.0%	67.0%	0.87	0.32
2042	100.0%	66.0%	0.86	0.31
2043	100.0%	65.0%	0.85	0.29
2044	100.0%	64.0%	0.85	0.28
2045	100.0%	63.0%	0.84	0.27
2046	100.0%	62.0%	0.84	0.26
2047	100.0%	61.0%	0.83	0.25
2048	100.0%	60.0%	0.82	0.25
2049	100.0%	59.0%	0.82	0.24
2050	100.0%	58.0%	0.81	0.23
2051	100.0%	57.0%	0.81	0.22
2052	100.0%	56.0%	0.80	0.21
2053	100.0%	55.0%	0.79	0.20
2054	100.0%	54.0%	0.79	0.20
2055	100.0%	53.0%	0.78	0.19
2056	100.0%	52.0%	0.78	0.18
2057	100.0%	51.0%	0.77	0.18
2058	100.0%	50.0%	0.77	0.17
2059	100.0%	49.0%	0.76	0.16
2060	100.0%	48.0%	0.75	0.16

2061	100.0%	47.0%	0.75	0.15
2062	100.0%	46.0%	0.74	0.15
2063	100.0%	45.0%	0.74	0.14
2064	100.0%	44.0%	0.73	0.14
2065	100.0%	43.0%	0.72	0.13
2066	100.0%	42.0%	0.72	0.13
2067	100.0%	41.0%	0.71	0.12
2068	100.0%	40.0%	0.71	0.12
2069	100.0%	39.0%	0.70	0.11
2070	100.0%	38.0%	0.69	0.11
2071	100.0%	37.0%	0.69	0.10
2072	100.0%	36.0%	0.68	0.10
2073	100.0%	35.0%	0.68	0.10
2074	100.0%	34.0%	0.67	0.09
2075	100.0%	33.0%	0.66	0.09
2076	100.0%	32.0%	0.66	0.09
2077	100.0%	31.0%	0.65	0.08
2078	100.0%	30.0%	0.65	0.08
2079	100.0%	29.0%	0.64	0.08
2080	100.0%	28.0%	0.64	0.07
2081	100.0%	27.0%	0.63	0.07
2082	100.0%	26.0%	0.62	0.07
2083	100.0%	25.0%	0.62	0.07
2084	100.0%	24.0%	0.61	0.06
2085	100.0%	23.0%	0.61	0.06
2086	100.0%	22.0%	0.60	0.06
2087	100.0%	21.0%	0.59	0.06
2088	100.0%	20.0%	0.59	0.05
2089	100.0%	19.0%	0.58	0.05
2090	100.0%	18.0%	0.58	0.05
2091	100.0%	17.0%	0.57	0.05
2092	100.0%	16.0%	0.56	0.05
2093	100.0%	15.0%	0.56	0.04
2094	100.0%	14.0%	0.55	0.04
2095	100.0%	13.0%	0.55	0.04
2096	100.0%	12.0%	0.54	0.04
2097	100.0%	11.0%	0.53	0.04

2098	100.0%	10.0%	0.53	0.04
2099	100.0%	9.0%	0.52	0.03
2100	100.0%	8.0%	0.52	0.03
2101	100.0%	7.0%	0.51	0.03
2102	100.0%	6.0%	0.51	0.03
2103	100.0%	5.0%	0.50	0.03
2104	100.0%	4.0%	0.49	0.03
2105	100.0%	3.0%	0.49	0.03
2106	100.0%	2.0%	0.48	0.03
2107	100.0%	1.0%	0.48	0.02
2108	100.0%	0.0%	0.47	0.02
Beyond				0.79
Total				29.12

Notes

Lost Functions are expressed as percentages for presentation purposes only.

Shaded values are linear interpolations.

"Beyond" indicates the remaining time horizon into perpetuity.

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Habitat Equivalency Analysis of Kilo Wharf
Lost Functions: West-East Extension

Annual Discount Rate: 3.0%

Present Year: 2007

Reef Flat/Crest

Habitat Impact (Acres)

Dredge/Fill:	2.466	(includes dredge, dredge buffer, fill, existing mooring, existing mooring buffer, and new mooring areas)
Anchor/Wire:	1.430	
Sedimentation:	1.830	
Sup Sediments:	18.380	(includes reef flat/slope)

	<-----Habitat Impact			----->	<-----(Acre-Years)	----->
Year	**Dredge/Fill**	**Anchor/Wire**	**Sedimentation**	**Sup Sediments**	**Current Value**	**Present Value**
2008	100.0%	100.0%	20.0%	5.0%	5.18	5.03
2009	100.0%	99.0%	20.0%	5.0%	5.17	4.87
2010	100.0%	98.0%	20.0%	5.0%	5.15	4.72
2011	100.0%	97.0%	17.5%	0	4.17	3.71
2012	100.0%	96.0%	15.0%		4.11	3.55
2013	100.0%	95.0%	12.5%		4.05	3.39
2014	100.0%	94.0%	10.0%		3.99	3.25
2015	100.0%	93.0%	7.5%		3.93	3.10
2016	100.0%	92.0%	5.0%		3.87	2.97
2017	100.0%	91.0%	2.5%		3.81	2.84
2018	100.0%	90.0%	0.0%		3.75	2.71
2019	100.0%	89.0%			3.74	2.62
2020	100.0%	88.0%			3.72	2.54
2021	100.0%	87.0%			3.71	2.45
2022	100.0%	86.0%			3.70	2.37
2023	100.0%	85.0%			3.68	2.29
2024	100.0%	84.0%			3.67	2.22
2025	100.0%	83.0%			3.65	2.15

2026	100.0%	82.0%	3.64	2.08
2027	100.0%	81.0%	3.62	2.01
2028	100.0%	80.0%	3.61	1.94
2029	100.0%	79.0%	3.60	1.88
2030	100.0%	78.0%	3.58	1.81
2031	100.0%	77.0%	3.57	1.75
2032	100.0%	76.0%	3.55	1.70
2033	100.0%	75.0%	3.54	1.64
2034	100.0%	74.0%	3.52	1.59
2035	100.0%	73.0%	3.51	1.53
2036	100.0%	72.0%	3.50	1.48
2037	100.0%	71.0%	3.48	1.43
2038	100.0%	70.0%	3.47	1.39
2039	100.0%	69.0%	3.45	1.34
2040	100.0%	68.0%	3.44	1.30
2041	100.0%	67.0%	3.42	1.25
2042	100.0%	66.0%	3.41	1.21
2043	100.0%	65.0%	3.40	1.17
2044	100.0%	64.0%	3.38	1.13
2045	100.0%	63.0%	3.37	1.10
2046	100.0%	62.0%	3.35	1.06
2047	100.0%	61.0%	3.34	1.02
2048	100.0%	60.0%	3.32	0.99
2049	100.0%	59.0%	3.31	0.96
2050	100.0%	58.0%	3.30	0.92
2051	100.0%	57.0%	3.28	0.89
2052	100.0%	56.0%	3.27	0.86
2053	100.0%	55.0%	3.25	0.84
2054	100.0%	54.0%	3.24	0.81
2055	100.0%	53.0%	3.22	0.78
2056	100.0%	52.0%	3.21	0.75
2057	100.0%	51.0%	3.20	0.73
2058	100.0%	50.0%	3.18	0.70
2059	100.0%	49.0%	3.17	0.68
2060	100.0%	48.0%	3.15	0.66
2061	100.0%	47.0%	3.14	0.64
2062	100.0%	46.0%	3.12	0.61

2063	100.0%	45.0%	3.11	0.59
2064	100.0%	44.0%	3.10	0.57
2065	100.0%	43.0%	3.08	0.55
2066	100.0%	42.0%	3.07	0.54
2067	100.0%	41.0%	3.05	0.52
2068	100.0%	40.0%	3.04	0.50
2069	100.0%	39.0%	3.02	0.48
2070	100.0%	38.0%	3.01	0.47
2071	100.0%	37.0%	3.00	0.45
2072	100.0%	36.0%	2.98	0.44
2073	100.0%	35.0%	2.97	0.42
2074	100.0%	34.0%	2.95	0.41
2075	100.0%	33.0%	2.94	0.39
2076	100.0%	32.0%	2.92	0.38
2077	100.0%	31.0%	2.91	0.37
2078	100.0%	30.0%	2.90	0.35
2079	100.0%	29.0%	2.88	0.34
2080	100.0%	28.0%	2.87	0.33
2081	100.0%	27.0%	2.85	0.32
2082	100.0%	26.0%	2.84	0.31
2083	100.0%	25.0%	2.82	0.30
2084	100.0%	24.0%	2.81	0.29
2085	100.0%	23.0%	2.79	0.28
2086	100.0%	22.0%	2.78	0.27
2087	100.0%	21.0%	2.77	0.26
2088	100.0%	20.0%	2.75	0.25
2089	100.0%	19.0%	2.74	0.24
2090	100.0%	18.0%	2.72	0.23
2091	100.0%	17.0%	2.71	0.23
2092	100.0%	16.0%	2.69	0.22
2093	100.0%	15.0%	2.68	0.21
2094	100.0%	14.0%	2.67	0.20
2095	100.0%	13.0%	2.65	0.20
2096	100.0%	12.0%	2.64	0.19
2097	100.0%	11.0%	2.62	0.18
2098	100.0%	10.0%	2.61	0.18
2099	100.0%	9.0%	2.59	0.17

2100	100.0%	8.0%	2.58	0.17
2101	100.0%	7.0%	2.57	0.16
2102	100.0%	6.0%	2.55	0.15
2103	100.0%	5.0%	2.54	0.15
2104	100.0%	4.0%	2.52	0.14
2105	100.0%	3.0%	2.51	0.14
2106	100.0%	2.0%	2.49	0.13
2107	100.0%	1.0%	2.48	0.13
2108	100.0%	0.0%	2.47	0.12
Beyond				4.15
Total				119.51

Reef Slope

Habitat Impact (Acres)
Dredge/Fill: 0.670 (includes dredge, dredge buffer, and fill areas)
Anchor/Wire: 1.160

	<-----------Habitat Impact----------->		<-------------(Acre-Years)------------->	
Year	**Dredge/Fill**	**Anchor/Wire**	**Current Value**	**Present Value**
2008	100.0%	100.0%	1.83	1.78
2009	100.0%	99.0%	1.82	1.71
2010	100.0%	98.0%	1.81	1.65
2011	100.0%	97.0%	1.80	1.60
2012	100.0%	96.0%	1.78	1.54
2013	100.0%	95.0%	1.77	1.48
2014	100.0%	94.0%	1.76	1.43
2015	100.0%	93.0%	1.75	1.38
2016	100.0%	92.0%	1.74	1.33
2017	100.0%	91.0%	1.73	1.28
2018	100.0%	90.0%	1.71	1.24
2019	100.0%	89.0%	1.70	1.19
2020	100.0%	88.0%	1.69	1.15
2021	100.0%	87.0%	1.68	1.11
2022	100.0%	86.0%	1.67	1.07
2023	100.0%	85.0%	1.66	1.03

2024	100.0%	84.0%	1.64	0.99
2025	100.0%	83.0%	1.63	0.96
2026	100.0%	82.0%	1.62	0.92
2027	100.0%	81.0%	1.61	0.89
2028	100.0%	80.0%	1.60	0.86
2029	100.0%	79.0%	1.59	0.83
2030	100.0%	78.0%	1.57	0.80
2031	100.0%	77.0%	1.56	0.77
2032	100.0%	76.0%	1.55	0.74
2033	100.0%	75.0%	1.54	0.71
2034	100.0%	74.0%	1.53	0.69
2035	100.0%	73.0%	1.52	0.66
2036	100.0%	72.0%	1.51	0.64
2037	100.0%	71.0%	1.49	0.62
2038	100.0%	70.0%	1.48	0.59
2039	100.0%	69.0%	1.47	0.57
2040	100.0%	68.0%	1.46	0.55
2041	100.0%	67.0%	1.45	0.53
2042	100.0%	66.0%	1.44	0.51
2043	100.0%	65.0%	1.42	0.49
2044	100.0%	64.0%	1.41	0.47
2045	100.0%	63.0%	1.40	0.46
2046	100.0%	62.0%	1.39	0.44
2047	100.0%	61.0%	1.38	0.42
2048	100.0%	60.0%	1.37	0.41
2049	100.0%	59.0%	1.35	0.39
2050	100.0%	58.0%	1.34	0.38
2051	100.0%	57.0%	1.33	0.36
2052	100.0%	56.0%	1.32	0.35
2053	100.0%	55.0%	1.31	0.34
2054	100.0%	54.0%	1.30	0.32
2055	100.0%	53.0%	1.28	0.31
2056	100.0%	52.0%	1.27	0.30
2057	100.0%	51.0%	1.26	0.29
2058	100.0%	50.0%	1.25	0.28
2059	100.0%	49.0%	1.24	0.27
2060	100.0%	48.0%	1.23	0.26

2061	100.0%	47.0%	1.22	0.25
2062	100.0%	46.0%	1.20	0.24
2063	100.0%	45.0%	1.19	0.23
2064	100.0%	44.0%	1.18	0.22
2065	100.0%	43.0%	1.17	0.21
2066	100.0%	42.0%	1.16	0.20
2067	100.0%	41.0%	1.15	0.19
2068	100.0%	40.0%	1.13	0.19
2069	100.0%	39.0%	1.12	0.18
2070	100.0%	38.0%	1.11	0.17
2071	100.0%	37.0%	1.10	0.17
2072	100.0%	36.0%	1.09	0.16
2073	100.0%	35.0%	1.08	0.15
2074	100.0%	34.0%	1.06	0.15
2075	100.0%	33.0%	1.05	0.14
2076	100.0%	32.0%	1.04	0.14
2077	100.0%	31.0%	1.03	0.13
2078	100.0%	30.0%	1.02	0.12
2079	100.0%	29.0%	1.01	0.12
2080	100.0%	28.0%	0.99	0.11
2081	100.0%	27.0%	0.98	0.11
2082	100.0%	26.0%	0.97	0.11
2083	100.0%	25.0%	0.96	0.10
2084	100.0%	24.0%	0.95	0.10
2085	100.0%	23.0%	0.94	0.09
2086	100.0%	22.0%	0.93	0.09
2087	100.0%	21.0%	0.91	0.09
2088	100.0%	20.0%	0.90	0.08
2089	100.0%	19.0%	0.89	0.08
2090	100.0%	18.0%	0.88	0.08
2091	100.0%	17.0%	0.87	0.07
2092	100.0%	16.0%	0.86	0.07
2093	100.0%	15.0%	0.84	0.07
2094	100.0%	14.0%	0.83	0.06
2095	100.0%	13.0%	0.82	0.06
2096	100.0%	12.0%	0.81	0.06
2097	100.0%	11.0%	0.80	0.06

2098	100.0%	10.0%	0.79	0.05
2099	100.0%	9.0%	0.77	0.05
2100	100.0%	8.0%	0.76	0.05
2101	100.0%	7.0%	0.75	0.05
2102	100.0%	6.0%	0.74	0.04
2103	100.0%	5.0%	0.73	0.04
2104	100.0%	4.0%	0.72	0.04
2105	100.0%	3.0%	0.70	0.04
2106	100.0%	2.0%	0.69	0.04
2107	100.0%	1.0%	0.68	0.04
2108	100.0%	0.0%	0.67	0.03
Beyond				1.13
Total				48.78

Notes

Lost Functions are expressed as percentages for presentation purposes only.

Shaded values are linear interpolations.

"Beyond" indicates the remaining time horizon into perpetuity.

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Habitat Equivalency Analysis of Kilo Wharf
Coral Diameters in Sella Bay

Station 3

Colonies/m^2 9.45

Reported		Indicated		Mid-Point	Total
<-----Greatest Diameter----->		<-------Diameter Class------->		Diameter	Diameter/m^2
(cm)	(proportion)	(cm)	(proportion)	(cm)	(cm)
<5	0.25	0 to <5	0.25	2.5	5.9
<20	0.80	5 to <20	0.55	12.5	65.0
≥40	0.07	20 to <40	0.13	30.0	36.9
≥80	0.01	40 to <80	0.06	60.0	34.0
		80 to <160	0.01	120.0	11.3
Total			1.00		153.1

Station 4

Colonies/m^2 36.87

Reported		Indicated		Mid-Point	Total
<-----Greatest Diameter----->		<-------Diameter Class------->		Diameter	Diameter/m^2
(cm)	(proportion)	(cm)	(proportion)	(cm)	(cm)
<5	0.43	0 to <5	0.43	2.5	39.6
<20	0.88	5 to <20	0.45	12.5	207.4
≥40	0.02	20 to <40	0.10	30.0	110.6
≥80	0.00	40 to <80	0.02	60.0	44.2
		80 to <160	0.00	120.0	0.0
Total			1.00		401.9

Station 5

Colonies/m² 32.53

Reported <-----Greatest Diameter-----> (cm)	(proportion)	Indicated <-------Diameter Class-------> (cm)	(proportion)	Mid-Point Diameter (cm)	Total Diameter/m² (cm)
<5	0.48	0 to <5	0.48	2.5	39.0
<20	0.95	5 to <20	0.47	12.5	191.1
≥40	0.01	20 to <40	0.04	30.0	39.0
≥80	0.00	40 to <80	0.01	60.0	19.5
		80 to <160	0.00	120.0	0.0
Total			1.00		288.7

Station 6

Colonies/m² 3.55

Reported <-----Greatest Diameter-----> (cm)	(proportion)	Indicated <-------Diameter Class-------> (cm)	(proportion)	Mid-Point Diameter (cm)	Total Diameter/m² (cm)
<5	0.70	0 to <5	0.70	2.5	6.2
<20	0.94	5 to <20	0.24	12.5	10.7
≥40	0.01	20 to <40	0.05	30.0	5.3
≥80	0.00	40 to <80	0.01	60.0	2.1
		80 to <160	0.00	120.0	0.0
Total			1.00		24.3

Station 7

Colonies/m^2 9.70

Reported		Indicated		Mid-Point	Total
<-----Greatest Diameter----->		<-------Diameter Class------->		Diameter	Diameter/m^2
(cm)	(proportion)	(cm)	(proportion)	(cm)	(cm)
<5	0.18	0 to <5	0.18	2.5	4.4
<20	0.61	5 to <20	0.43	12.5	52.1
≥40	0.18	20 to <40	0.21	30.0	61.1
≥80	0.06	40 to <80	0.12	60.0	69.8
		80 to <160	0.06	120.0	69.8
Total			1.00		257.3

Station 8

Colonies/m^2 19.23

Reported		Indicated		Mid-Point	Total
<-----Greatest Diameter----->		<-------Diameter Class------->		Diameter	Diameter/m^2
(cm)	(proportion)	(cm)	(proportion)	(cm)	(cm)
<5	0.24	0 to <5	0.24	2.5	11.5
<20	0.80	5 to <20	0.56	12.5	134.6
≥40	0.05	20 to <40	0.15	30.0	86.5
≥80	0.01	40 to <80	0.04	60.0	46.2
		80 to <160	0.01	120.0	23.1
Total			1.00		301.9

Station 9

Colonies/m^2 9.75

Reported		Indicated		Mid-Point	Total
<-----Greatest Diameter----->		<-------Diameter Class------->		Diameter	Diameter/m^2
(cm)	(proportion)	(cm)	(proportion)	(cm)	(cm)
<5	0.31	0 to <5	0.31	2.5	7.6
<20	0.84	5 to <20	0.53	12.5	64.6
≥40	0.16	20 to <40	0.00	30.0	0.0
≥80	0.06	40 to <80	0.10	60.0	58.5
		80 to <160	0.06	120.0	70.2
Total			1.00		200.9

Station 10

Colonies/m^2 19.77

Reported		Indicated		Mid-Point	Total
<-----Greatest Diameter----->		<-------Diameter Class------->		Diameter	Diameter/m^2
(cm)	(proportion)	(cm)	(proportion)	(cm)	(cm)
<5	0.19	0 to <5	0.19	2.5	9.4
<20	0.72	5 to <20	0.53	12.5	131.0
≥40	0.09	20 to <40	0.19	30.0	112.7
≥80	0.02	40 to <80	0.07	60.0	83.0
		80 to <160	0.02	120.0	47.4
Total			1.00		383.5

Station 11

Colonies/m^2 13.90

Reported		Indicated		Mid-Point	Total
<-----Greatest Diameter----->		<-------Diameter Class------->		Diameter	Diameter/m^2
(cm)	(proportion)	(cm)	(proportion)	(cm)	(cm)
<5	0.30	0 to <5	0.30	2.5	10.4
<20	0.82	5 to <20	0.52	12.5	90.4
≥40	0.06	20 to <40	0.12	30.0	50.0
≥80	0.01	40 to <80	0.05	60.0	41.7
		80 to <160	0.01	120.0	16.7
Total			1.00		209.2

Station 12

Colonies/m^2 13.93

Reported		Indicated		Mid-Point	Total
<-----Greatest Diameter----->		<-------Diameter Class------->		Diameter	Diameter/m^2
(cm)	(proportion)	(cm)	(proportion)	(cm)	(cm)
<5	0.38	0 to <5	0.38	2.5	13.2
<20	0.82	5 to <20	0.44	12.5	76.6
≥40	0.06	20 to <40	0.12	30.0	50.1
≥80	0.04	40 to <80	0.02	60.0	16.7
		80 to <160	0.04	120.0	66.9
Total			1.00		223.6

Average Diameter/m^2

Zone	Inclusive Stations	Total Area (acres)	Average Diameter/m^2 (cm)
1		0.70	
2		0.82	
3		2.77	
4	6	1.59	24.32
5	3	0.27	153.09
6	11	2.93	209.20
7	9	2.06	200.85
8	8, 10	4.95	342.72
9	7, 12	1.87	240.43
10		1.56	
11	4, 5	0.97	345.29
12		1.11	

Habitat	Inclusive Zones	Average Diameter/m^2 (cm)
Reef Flat/Crest	1, 2, 3, 4, 11, 12	145.94
Reef Slope	5, 6, 8, 10	288.44

Notes

The largest coral diameters are reported in Brown and Kolinski (2006) as "160 +" centimeters. For purposes of determining mid-point diameters, the largest indicated diameter class was bounded in this analysis at 160 centimeters. Any downward bias resulting from this approach is minimized by the fact that very few coral colonies occur in that class.

The average diameter/m^2 for each zone is the arithmetic mean of the total diameters/m^2 for inclusive stations.

The average diameter/m^2 for each habitat is the mean of inclusive zones, weighted by acreage.

Habitat Equivalency Analysis of Kilo Wharf
Coral Diameters at Kilo Wharf

Station 1

<-------Diameter Class------->		Mid-Point Diameter	Total Diameter/m^2
(cm)	(colonies/m^2)	(cm)	(cm)
0 to <5	1.80	2.5	4.5
5 to <20	1.93	12.5	24.1
20 to <40	0.30	30.0	9.0
40 to <80	0.05	60.0	3.0
80 to <160	0.00	120.0	0.0
			40.6

Station 2

<-------Diameter Class------->		Mid-Point Diameter	Total Diameter/m^2
(cm)	(colonies/m^2)	(cm)	(cm)
0 to <5	2.30	2.5	5.8
5 to <20	1.65	12.5	20.6
20 to <40	0.25	30.0	7.5
40 to <80	0.00	60.0	0.0
80 to <160	0.00	120.0	0.0
			33.9

Station 3

<-------Diameter Class------->		Mid-Point Diameter	Total Diameter/m^2
(cm)	(colonies/m^2)	(cm)	(cm)
0 to <5	0.98	2.5	2.4
5 to <20	1.05	12.5	13.1
20 to <40	0.18	30.0	5.3
40 to <80	0.05	60.0	3.0
80 to <160	0.00	120.0	0.0
			23.8

Station 4

<-------Diameter Class-------> (cm)	(colonies/m²)	Mid-Point Diameter (cm)	Total Diameter/m² (cm)
0 to <5	0.83	2.5	2.1
5 to <20	1.38	12.5	17.2
20 to <40	0.48	30.0	14.3
40 to <80	0.30	60.0	18.0
80 to <160	0.00	120.0	0.0
			51.5

Station 5

<-------Diameter Class-------> (cm)	(colonies/m²)	Mid-Point Diameter (cm)	Total Diameter/m² (cm)
0 to <5	0.48	2.5	1.2
5 to <20	4.08	12.5	50.9
20 to <40	2.48	30.0	74.3
40 to <80	1.85	60.0	111.0
80 to <160	0.58	120.0	69.0
			306.4

Station 6

<-------Diameter Class-------> (cm)	(colonies/m²)	Mid-Point Diameter (cm)	Total Diameter/m² (cm)
0 to <5	1.45	2.5	3.6
5 to <20	4.05	12.5	50.6
20 to <40	2.08	30.0	62.3
40 to <80	0.78	60.0	46.5
80 to <160	0.08	120.0	9.0
			172.0

Station 7

<-------Diameter Class-------> (cm)	(colonies/m²)	Mid-Point Diameter (cm)	Total Diameter/m² (cm)
0 to <5	0.28	2.5	0.7
5 to <20	2.40	12.5	30.0
20 to <40	1.28	30.0	38.3
40 to <80	1.15	60.0	69.0
80 to <160	1.05	120.0	126.0
			263.9

Station 8

<-------Diameter Class-------> (cm)	(colonies/m^2)	Mid-Point Diameter (cm)	Total Diameter/m^2 (cm)
0 to <5	1.20	2.5	3.0
5 to <20	4.45	12.5	55.6
20 to <40	1.65	30.0	49.5
40 to <80	1.45	60.0	87.0
80 to <160	0.75	120.0	90.0
			285.1

Station 9

<-------Diameter Class-------> (cm)	(colonies/m^2)	Mid-Point Diameter (cm)	Total Diameter/m^2 (cm)
0 to <5	1.13	2.5	2.8
5 to <20	1.08	12.5	13.4
20 to <40	0.58	30.0	17.3
40 to <80	0.03	60.0	1.5
80 to <160	0.00	120.0	0.0
			35.0

Station 10

<-------Diameter Class-------> (cm)	(colonies/m^2)	Mid-Point Diameter (cm)	Total Diameter/m^2 (cm)
0 to <5	0.13	2.5	0.3
5 to <20	0.40	12.5	5.0
20 to <40	0.00	30.0	0.0
40 to <80	0.00	60.0	0.0
80 to <160	0.00	120.0	0.0
			5.3

Station 11

<-------Diameter Class-------> (cm)	(colonies/m^2)	Mid-Point Diameter (cm)	Total Diameter/m^2 (cm)
0 to <5	0.90	2.5	2.3
5 to <20	2.05	12.5	25.6
20 to <40	0.78	30.0	23.3
40 to <80	0.25	60.0	15.0
80 to <160	0.05	120.0	6.0
			72.1

Station 12

<-------Diameter Class-------> (cm)	(colonies/m^2)	Mid-Point Diameter (cm)	Total Diameter/m^2 (cm)
0 to <5	1.88	2.5	4.7
5 to <20	4.83	12.5	60.3
20 to <40	2.03	30.0	60.8
40 to <80	1.40	60.0	84.0
80 to <160	0.78	120.0	93.0
			302.8

Station 13

<-------Diameter Class-------> (cm)	(colonies/m^2)	Mid-Point Diameter (cm)	Total Diameter/m^2 (cm)
0 to <5	1.00	2.5	2.5
5 to <20	1.40	12.5	17.5
20 to <40	0.08	30.0	2.3
40 to <80	0.03	60.0	1.5
80 to <160	0.00	120.0	0.0
			23.8

Station 14

<-------Diameter Class-------> (cm)	(colonies/m^2)	Mid-Point Diameter (cm)	Total Diameter/m^2 (cm)
0 to <5	0.58	2.5	1.4
5 to <20	1.98	12.5	24.7
20 to <40	0.88	30.0	26.3
40 to <80	0.68	60.0	40.5
80 to <160	0.90	120.0	108.0
			200.9

Station 15

<-------Diameter Class-------> (cm)	(colonies/m^2)	Mid-Point Diameter (cm)	Total Diameter/m^2 (cm)
0 to <5	2.43	2.5	6.1
5 to <20	6.30	12.5	78.8
20 to <40	2.77	30.0	83.0
40 to <80	0.97	60.0	58.0
80 to <160	0.13	120.0	16.0
			241.8

Station 16

<-------Diameter Class-------> (cm)	(colonies/m^2)	Mid-Point Diameter (cm)	Total Diameter/m^2 (cm)
0 to <5	4.25	2.5	10.6
5 to <20	3.13	12.5	39.1
20 to <40	1.78	30.0	53.3
40 to <80	0.98	60.0	58.5
80 to <160	0.33	120.0	39.0
			200.4

Average Diameter/m^2

	<------Western Extension------>		<-----West-East Extension----->	
Habitat	Inclusive Stations	Average Diameter/m^2 (cm)	Inclusive Stations	Average Diameter/m^2 (cm)
Reef Flat/Crest	1, 2, 5, 6, 11, 15, 16	152.46	1, 2, 5, 6, 9, 11, 15, 16	137.78
Reef Slope	3, 4, 13, 14	74.98	3, 4, 7, 8, 13, 14	141.50

Notes

The largest coral diameters are reported by Kolinski (pers. com., 10/18/06) as "160 +" centimeters. For purposes of determining mid-point diameters, the largest indicated diameter class was bounded in this analysis at 160 centimeters. Any downward bias resulting from this approach is minimized by the fact that very few coral colonies occur in that class.

The average diameter/m^2 for each habitat and alternative is the arithmetic mean of the total diameters/m^2 for inclusive stations.

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Habitat Equivalency Analysis of Kilo Wharf
Expected Replacement Functions: Western Extension

Relative Productivity

Annual Discount Rate:	3.0%
Present Year:	2007
Maximum Relative Productivity	
Reef Flat/Crest:	95.7%
Reef Slope:	384.7%

	<----------Reef Flat/Crest---------->		<-------------Reef Slope------------->	
Year	**Current Value**	**Present Value**	**Current Value**	**Present Value**
2008	0.0%	0.0%	0.0%	0.0%
2009	0.0%	0.0%	0.0%	0.0%
2010	0.0%	0.0%	0.0%	0.0%
2011	0.0%	0.0%	0.0%	0.0%
2012	0.0%	0.0%	0.0%	0.0%
2013	0.0%	0.0%	0.0%	0.0%
2014	0.0%	0.0%	0.0%	0.0%
2015	0.0%	0.0%	0.0%	0.0%
2016	0.0%	0.0%	0.0%	0.0%
2017	0.0%	0.0%	0.0%	0.0%
2018	0.0%	0.0%	0.0%	0.0%
2019	1.0%	0.7%	3.8%	2.7%
2020	1.9%	1.3%	7.7%	5.2%
2021	2.9%	1.9%	11.5%	7.6%
2022	3.8%	2.5%	15.4%	9.9%
2023	4.8%	3.0%	19.2%	12.0%
2024	5.7%	3.5%	23.1%	14.0%
2025	6.7%	3.9%	26.9%	15.8%
2026	7.7%	4.4%	30.8%	17.5%
2027	8.6%	4.8%	34.6%	19.2%
2028	9.6%	5.1%	38.5%	20.7%
2029	10.5%	5.5%	42.3%	22.1%
2030	11.5%	5.8%	46.2%	23.4%
2031	12.4%	6.1%	50.0%	24.6%
2032	13.4%	6.4%	53.9%	25.7%
2033	14.4%	6.7%	57.7%	26.8%
2034	15.3%	6.9%	61.5%	27.7%
2035	16.3%	7.1%	65.4%	28.6%
2036	17.2%	7.3%	69.2%	29.4%
2037	18.2%	7.5%	73.1%	30.1%
2038	19.1%	7.7%	76.9%	30.8%
2039	20.1%	7.8%	80.8%	31.4%
2040	21.1%	7.9%	84.6%	31.9%
2041	22.0%	8.1%	88.5%	32.4%
2042	23.0%	8.2%	92.3%	32.8%

2043	23.9%	8.3%	96.2%	33.2%
2044	24.9%	8.3%	100.0%	33.5%
2045	25.8%	8.4%	103.9%	33.8%
2046	26.8%	8.5%	107.7%	34.0%
2047	27.8%	8.5%	111.6%	34.2%
2048	28.7%	8.5%	115.4%	34.3%
2049	29.7%	8.6%	119.2%	34.5%
2050	30.6%	8.6%	123.1%	34.5%
2051	31.6%	8.6%	126.9%	34.6%
2052	32.5%	8.6%	130.8%	34.6%
2053	33.5%	8.6%	134.6%	34.6%
2054	34.5%	8.6%	138.5%	34.5%
2055	35.4%	8.6%	142.3%	34.4%
2056	36.4%	8.5%	146.2%	34.3%
2057	37.3%	8.5%	150.0%	34.2%
2058	38.3%	8.5%	153.9%	34.1%
2059	39.2%	8.4%	157.7%	33.9%
2060	40.2%	8.4%	161.6%	33.7%
2061	41.2%	8.3%	165.4%	33.5%
2062	42.1%	8.3%	169.3%	33.3%
2063	43.1%	8.2%	173.1%	33.1%
2064	44.0%	8.2%	176.9%	32.8%
2065	45.0%	8.1%	180.8%	32.6%
2066	45.9%	8.0%	184.6%	32.3%
2067	46.9%	8.0%	188.5%	32.0%
2068	47.9%	7.9%	192.3%	31.7%
2069	48.8%	7.8%	196.2%	31.4%
2070	49.8%	7.7%	200.0%	31.1%
2071	50.7%	7.7%	203.9%	30.7%
2072	51.7%	7.6%	207.7%	30.4%
2073	52.6%	7.5%	211.6%	30.1%
2074	53.6%	7.4%	215.4%	29.7%
2075	54.6%	7.3%	219.3%	29.4%
2076	55.5%	7.2%	223.1%	29.0%
2077	56.5%	7.1%	227.0%	28.7%
2078	57.4%	7.0%	230.8%	28.3%
2079	58.4%	7.0%	234.6%	27.9%
2080	59.3%	6.9%	238.5%	27.6%
2081	60.3%	6.8%	242.3%	27.2%
2082	61.3%	6.7%	246.2%	26.8%
2083	62.2%	6.6%	250.0%	26.4%
2084	63.2%	6.5%	253.9%	26.1%
2085	64.1%	6.4%	257.7%	25.7%
2086	65.1%	6.3%	261.6%	25.3%
2087	66.0%	6.2%	265.4%	24.9%
2088	67.0%	6.1%	269.3%	24.6%
2089	68.0%	6.0%	273.1%	24.2%
2090	68.9%	5.9%	277.0%	23.8%
2091	69.9%	5.8%	280.8%	23.4%
2092	70.8%	5.7%	284.7%	23.1%
2093	71.8%	5.7%	288.5%	22.7%
2094	72.7%	5.6%	292.3%	22.3%

2095	73.7%	5.5%	296.2%	22.0%
2096	74.7%	5.4%	300.0%	21.6%
2097	75.6%	5.3%	303.9%	21.2%
2098	76.6%	5.2%	307.7%	20.9%
2099	77.5%	5.1%	311.6%	20.5%
2100	78.5%	5.0%	315.4%	20.2%
2101	79.4%	4.9%	319.3%	19.8%
2102	80.4%	4.9%	323.1%	19.5%
2103	81.4%	4.8%	327.0%	19.1%
2104	82.3%	4.7%	330.8%	18.8%
2105	83.3%	4.6%	334.7%	18.5%
2106	84.2%	4.5%	338.5%	18.1%
2107	85.2%	4.4%	342.3%	17.8%
2108	86.2%	4.4%	346.2%	17.5%
2109	87.1%	4.3%	350.0%	17.2%
2110	88.1%	4.2%	353.9%	16.9%
2111	89.0%	4.1%	357.7%	16.5%
2112	90.0%	4.0%	361.6%	16.2%
2113	90.9%	4.0%	365.4%	15.9%
2114	91.9%	3.9%	369.3%	15.6%
2115	92.9%	3.8%	373.1%	15.3%
2116	93.8%	3.7%	377.0%	15.0%
2117	94.8%	3.7%	380.8%	14.7%
2118	95.7%	3.6%	384.7%	14.5%
Beyond		119.9%		482.0%
Total		750.2%		3014.8%

Expected Replacement Functions

Habitat	Area (Acres)	Probability of Mitigation Success	Total Expected Replacement Functions (Acre-Years)
Reef Flat/Crest	7.5	100%	56.3
		75%	42.2
		50%	28.1
Reef Slope	10.7	100%	322.6
		75%	241.9
		50%	161.3

Notes

Relative productivities are expressed as percentages for presentation purposes only.

Shaded values are linear interpolations.

"Beyond" indicates the remaining time horizon into perpetuity.

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Habitat Equivalency Analysis of Kilo Wharf
Expected Replacement Functions: West-East Extension

Relative Productivity

Annual Discount Rate: 3.0%

Present Year: 2007

Maximum Relative Productivity
Reef Flat/Crest: 105.9%
Reef Slope: 203.8%

	<----------Reef Flat/Crest---------->		<-------------Reef Slope------------->	
Year	**Current Value**	**Present Value**	**Current Value**	**Present Value**
2008	0.0%	0.0%	0.0%	0.0%
2009	0.0%	0.0%	0.0%	0.0%
2010	0.0%	0.0%	0.0%	0.0%
2011	0.0%	0.0%	0.0%	0.0%
2012	0.0%	0.0%	0.0%	0.0%
2013	0.0%	0.0%	0.0%	0.0%
2014	0.0%	0.0%	0.0%	0.0%
2015	0.0%	0.0%	0.0%	0.0%
2016	0.0%	0.0%	0.0%	0.0%
2017	0.0%	0.0%	0.0%	0.0%
2018	0.0%	0.0%	0.0%	0.0%
2019	1.1%	0.7%	2.0%	1.4%
2020	2.1%	1.4%	4.1%	2.8%
2021	3.2%	2.1%	6.1%	4.0%
2022	4.2%	2.7%	8.2%	5.2%
2023	5.3%	3.3%	10.2%	6.4%
2024	6.4%	3.8%	12.2%	7.4%
2025	7.4%	4.4%	14.3%	8.4%
2026	8.5%	4.8%	16.3%	9.3%
2027	9.5%	5.3%	18.3%	10.2%
2028	10.6%	5.7%	20.4%	11.0%
2029	11.7%	6.1%	22.4%	11.7%
2030	12.7%	6.4%	24.5%	12.4%
2031	13.8%	6.8%	26.5%	13.0%
2032	14.8%	7.1%	28.5%	13.6%
2033	15.9%	7.4%	30.6%	14.2%
2034	16.9%	7.6%	32.6%	14.7%
2035	18.0%	7.9%	34.7%	15.1%
2036	19.1%	8.1%	36.7%	15.6%
2037	20.1%	8.3%	38.7%	16.0%
2038	21.2%	8.5%	40.8%	16.3%
2039	22.2%	8.6%	42.8%	16.6%
2040	23.3%	8.8%	44.8%	16.9%
2041	24.4%	8.9%	46.9%	17.2%
2042	25.4%	9.0%	48.9%	17.4%

2043	26.5%	9.1%	51.0%	17.6%
2044	27.5%	9.2%	53.0%	17.8%
2045	28.6%	9.3%	55.0%	17.9%
2046	29.7%	9.4%	57.1%	18.0%
2047	30.7%	9.4%	59.1%	18.1%
2048	31.8%	9.5%	61.2%	18.2%
2049	32.8%	9.5%	63.2%	18.3%
2050	33.9%	9.5%	65.2%	18.3%
2051	35.0%	9.5%	67.3%	18.3%
2052	36.0%	9.5%	69.3%	18.3%
2053	37.1%	9.5%	71.3%	18.3%
2054	38.1%	9.5%	73.4%	18.3%
2055	39.2%	9.5%	75.4%	18.3%
2056	40.3%	9.5%	77.5%	18.2%
2057	41.3%	9.4%	79.5%	18.1%
2058	42.4%	9.4%	81.5%	18.1%
2059	43.4%	9.3%	83.6%	18.0%
2060	44.5%	9.3%	85.6%	17.9%
2061	45.5%	9.2%	87.7%	17.8%
2062	46.6%	9.2%	89.7%	17.6%
2063	47.7%	9.1%	91.7%	17.5%
2064	48.7%	9.0%	93.8%	17.4%
2065	49.8%	9.0%	95.8%	17.3%
2066	50.8%	8.9%	97.8%	17.1%
2067	51.9%	8.8%	99.9%	17.0%
2068	53.0%	8.7%	101.9%	16.8%
2069	54.0%	8.6%	104.0%	16.6%
2070	55.1%	8.6%	106.0%	16.5%
2071	56.1%	8.5%	108.0%	16.3%
2072	57.2%	8.4%	110.1%	16.1%
2073	58.3%	8.3%	112.1%	15.9%
2074	59.3%	8.2%	114.2%	15.8%
2075	60.4%	8.1%	116.2%	15.6%
2076	61.4%	8.0%	118.2%	15.4%
2077	62.5%	7.9%	120.3%	15.2%
2078	63.6%	7.8%	122.3%	15.0%
2079	64.6%	7.7%	124.3%	14.8%
2080	65.7%	7.6%	126.4%	14.6%
2081	66.7%	7.5%	128.4%	14.4%
2082	67.8%	7.4%	130.5%	14.2%
2083	68.9%	7.3%	132.5%	14.0%
2084	69.9%	7.2%	134.5%	13.8%
2085	71.0%	7.1%	136.6%	13.6%
2086	72.0%	7.0%	138.6%	13.4%
2087	73.1%	6.9%	140.7%	13.2%
2088	74.1%	6.8%	142.7%	13.0%
2089	75.2%	6.7%	144.7%	12.8%
2090	76.3%	6.6%	146.8%	12.6%
2091	77.3%	6.5%	148.8%	12.4%
2092	78.4%	6.4%	150.8%	12.2%
2093	79.4%	6.3%	152.9%	12.0%
2094	80.5%	6.2%	154.9%	11.8%

2095	81.6%	6.1%	157.0%	11.6%
2096	82.6%	6.0%	159.0%	11.5%
2097	83.7%	5.9%	161.0%	11.3%
2098	84.7%	5.8%	163.1%	11.1%
2099	85.8%	5.7%	165.1%	10.9%
2100	86.9%	5.6%	167.2%	10.7%
2101	87.9%	5.5%	169.2%	10.5%
2102	89.0%	5.4%	171.2%	10.3%
2103	90.0%	5.3%	173.3%	10.1%
2104	91.1%	5.2%	175.3%	10.0%
2105	92.2%	5.1%	177.3%	9.8%
2106	93.2%	5.0%	179.4%	9.6%
2107	94.3%	4.9%	181.4%	9.4%
2108	95.3%	4.8%	183.5%	9.3%
2109	96.4%	4.7%	185.5%	9.1%
2110	97.4%	4.6%	187.5%	8.9%
2111	98.5%	4.6%	189.6%	8.8%
2112	99.6%	4.5%	191.6%	8.6%
2113	100.6%	4.4%	193.7%	8.4%
2114	101.7%	4.3%	195.7%	8.3%
2115	102.7%	4.2%	197.7%	8.1%
2116	103.8%	4.1%	199.8%	8.0%
2117	104.9%	4.1%	201.8%	7.8%
2118	105.9%	4.0%	203.8%	7.7%
Beyond		132.7%		255.4%
Total		830.2%		1597.6%

Expected Replacement Functions

Habitat	Area (Acres)	Probability of Mitigation Success	Total Expected Replacement Functions (Acre-Years)
Reef Flat/Crest	7.5	100%	62.3
		75%	46.7
		50%	31.1
Reef Slope	10.7	100%	170.9
		75%	128.2
		50%	85.5

Notes

Relative productivities are expressed as percentages for presentation purposes only.

Shaded values are linear interpolations.

"Beyond" indicates the remaining time horizon into perpetuity.

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Appendix 2

Derivation and Interpretation of the Habitat Equivalency Analysis Solution Incorporating Mitigation Uncertainty

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Derivation and Interpretation of the Habitat Equivalency Analysis Solution Incorporating Mitigation Uncertainty

Derivation of the Solution

Given mitigation uncertainty, the compensation criterion behind Habitat Equivalency Analysis (HEA) is characterized by the following relationship.

$$V^L \sum_{t=t_0}^{t_1} L_t (1+i)^{(P-t)} \quad = \quad aV^R \sum_{s=s_0}^{s_1} R_s (1+i)^{(P-s)} \qquad [1]$$

Where	L_t	=	Lost functions in time period t
	V^L	=	Total economic value per unit of lost functions (assumed to be invariant with respect to the scale of lost functions and time)
	a	=	Probability of mitigation success
	R_s	=	Replacement functions in time period s
	V^R	=	Total economic value per unit of replacement functions (assumed to be invariant with respect to the scale of replacement functions and time)
	t_0	=	Time period when lost functions first occur
	t_1	=	Time period when lost functions last occur
	s_0	=	Time period when replacement functions first occur
	s_1	=	Time period when replacement functions last occur
	P	=	Present time period (generally when the analysis is conducted)
	i	=	Periodic discount rate

This criterion requires that the ***uncertain*** (or expected) value of replacement functions from mitigation be sufficient to offset the ***certain*** value of lost functions from project impacts. The expression on the left hand side of equation [1] is the total present value of lost functions and the expression on the right hand side is the expected total present value of replacement functions provided by compensatory mitigation. Thus, sufficient replacement functions, R_s, must be provided through time to generate an expected total present value that is equal to the total present value of lost functions. The uncertain nature of mitigation is captured in this model by the probability of mitigation success (a).

HEA is a specific application of this criterion. The simplifying assumption that is required for HEA is that the replacement functions provided by compensatory mitigation are comparable to the lost functions. Specifically, HEA assumes that V^R equals V^L, which simplifies equation [1] as follows.

$$\sum_{t=t_0}^{t_1} L_t (1+i)^{(P-t)} = a \sum_{s=s_0}^{s_1} R_s (1+i)^{(P-s)} \qquad [2]$$

Thus, the value terms cancel out, avoiding economic valuation while continuing to satisfy the compensation criterion.

If a constant level of replacement functions, R, is provided through time, then equation [2] can be modified to allow for the unique solution of the compensatory mitigation requirement.

$$\sum_{t=t_0}^{t_1} L_t (1+i)^{(P-t)} = a \sum_{s=s_0}^{s_1} R (1+i)^{(P-s)}$$

$$= aR \sum_{s=s_0}^{s_1} (1+i)^{(P-s)}$$

$$R = \frac{\sum_{t=t_0}^{t_1} L_t (1+i)^{(P-t)}}{a \sum_{s=s_0}^{s_1} (1+i)^{(P-s)}}$$

Replacement functions are often quantified by habitat area (e.g., acres). Given that metric, varying levels of effective function provision can be accommodated by assigning varying proportional weights, Q_s, to a constant habitat area, R, through time. For example, such weights could reflect the increasing efficacy of compensatory mitigation as planted vegetation grows or is succeeded by the intended climax community. These weights are referred to as ***relative productivity***.

$$\sum_{t=t_0}^{t_1} L_t (1+i)^{(P-t)} = a \sum_{s=s_0}^{s_1} Q_s R (1+i)^{(P-s)}$$

$$= aR \sum_{s=s_0}^{s_1} Q_s (1+i)^{(P-s)}$$

$$R = \frac{\sum_{t=t_0}^{t_1} L_t (1+i)^{(P-t)}}{a \sum_{s=s_0}^{s_1} Q_s (1+i)^{(P-s)}} \qquad [3]$$

Where Q_s = Relative productivity (proportional equivalence of the net ecological functions provided in time period *s* by compensatory mitigation relative to the baseline functions of the affected habitat)

Equation [3] is used to determine the scale of compensatory mitigation when both lost functions and replacement functions occur over finite time horizons. Modifications of that equation include situations where some level of lost functions continues into perpetuity, and where compensatory mitigation provides some level of replacement functions into perpetuity.

In situations where a constant level of lost functions continues into perpetuity, but where replacement functions occur over a finite time horizon, the appropriate calculation is given in equation [4] below.

$$R = \frac{\sum_{t=t_0}^{t_1} L_t (1+i)^{(P-t)} + \frac{L_{t_1} (1+i)^{(P-t_1)}}{i}}{a \sum_{s=s_0}^{s_1} Q_s (1+i)^{(P-s)}} \qquad [4]$$

Where t_1 = Time period when a constant level of lost functions is achieved

L_{t_1} = Constant level of lost functions continuing from time period t_1 into perpetuity

All other variables are as defined for equation [3] above.

In situations where compensatory mitigation provides a constant level of replacement functions into perpetuity, but where lost functions occur over a finite time horizon, the appropriate calculation is given in equation [5] below.

$$R = \frac{\sum_{t=t_0}^{t_1} L_t (1+i)^{(P-t)}}{a\sum_{s=s_0}^{s_1} Q_s (1+i)^{(P-s)} + \frac{aQ_{s_1}(1+i)^{(P-s_1)}}{i}} \qquad [5]$$

Where s_1 = Time period when compensatory mitigation achieves a constant level of replacement functions

Q_{s_1} = Constant level of relative productivity continuing from time period s_1 into perpetuity

All other variables are as defined for equation [3] above.

Finally, in situations where a constant level of lost functions continues into perpetuity, and where compensatory mitigation provides a constant level of replacement functions into perpetuity, the appropriate calculation is given in equation [6] below.

$$R = \frac{\sum_{t=t_0}^{t_1} L_t (1+i)^{(P-t)} + \frac{L_{t_1}(1+i)^{(P-t_1)}}{i}}{a\sum_{s=s_0}^{s_1} Q_s (1+i)^{(P-s)} + \frac{aQ_{s_1}(1+i)^{(P-s_1)}}{i}} \qquad [6]$$

Where t_1 = Time period when a constant level of lost functions is achieved

L_{t_1} = Constant level of lost functions continuing from time period t_1 into perpetuity

s_1 = Time period when compensatory mitigation achieves a constant level of replacement functions

Q_{s_1} = Constant level of relative productivity continuing from time period s_1 into perpetuity

All other variables are as defined for equation [3] above.

Interpretation of the Solution

The following expression obtains directly from equation [3].

$$a\sum_{s=s_0}^{s_1} Q_s(1+i)^{(P-s)} \quad = \quad \frac{\sum_{t=t_0}^{t_1} L_t(1+i)^{(P-t)}}{R} \qquad [7]$$

The left hand side of equation [7] is the expected total present value of relative productivity, where Q_s is a proportion describing the level of effective function provision in time period *s*. The right hand side of equation [7] is the total present value of lost functions divided by the required habitat area of compensatory mitigation. Since the expected total present value of replacement functions must equal the total present value of lost functions (equation [2]), the right hand side of equation [7] is the expected total present value of replacement functions provided by each unit of compensatory mitigation. In other words, equation [7] equates the expected total present value of relative productivity with the expected total present value of replacement functions provided by each unit of compensatory mitigation.

Therefore, equation [3] takes on an intuitive interpretation: that the required habitat area of compensatory mitigation equals the total present value of lost functions divided by the expected total present value of replacement functions provided by each unit of compensatory mitigation. The same interpretation also applies to equations [4], [5], and [6].

Note on Compensatory Mitigation with a Fixed Size

The derivation of the HEA solution presented above assumes that compensatory mitigation is continuously scalable. That is, the size of compensatory mitigation is assumed to be incrementally adjustable in order to produce a quantity of replacement functions that is equal to the quantity of lost functions resulting from project impacts. However, that assumption is not valid if the size of compensatory mitigation is fixed by geomorphologic or other constraining factors.

Given a fixed size of compensatory mitigation, the relevant question to be addressed by HEA is whether the fixed size can produce a sufficient quantity of replacement functions to offset (rather than equal) the quantity of lost functions. For example, from equation [3], that criterion is satisfied if the following relationship holds.

$$aR\sum_{s=s_0}^{s_1} Q_s(1+i)^{(P-s)} \quad \geq \quad \sum_{t=t_0}^{t_1} L_t(1+i)^{(P-t)}$$