Proposal for data collection, monitoring and assessment of the red sea urchin fishery in California

For the California Sea Urchin Commission

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Executive Summary

Given the small-scale spatial structure of sea urchin populations in California, data collection and analyses should be done at appropriate scales to depict spatial and temporal trends in performance indicators. In this report, I summarize the type and spatial resolution of both fishery-dependent and fishery-independent information needed to monitor the state of the resource and its fishery. Although I acknowledge economic difficulties associated with gathering high spatial resolution data, I suggest that information on at least catch, effort and size frequency distribution of the catch should be taken at the port-level. Databases may be enhanced substantially if the management agency (through complete and spatially-explicit log-book information), the industry (through sampling of the catches both at landing sites and at processing plant) and divers (though community-based data collection program) all get involved in collecting and eventually analyzing the information. Considering a general weak correlation between catch statistics and actual biomasses and densities, especially in highly aggregated sedentary resources, fishery independent data should be also taken. This information would allow more accurate and reliable knowledge on the status of the resource as well as calibration of the fishery independent information and data collection procedures. Finally, efforts on sampling and surveys should be directed also to those areas outside the fishing grounds to determine what fraction of the total population is under exploitation. Tables 2 and 3 show what would be an ideal and comprehensive data collection program for this fishery.

As importantly as the information mentioned before, and given the characteristics of the fishery and previous analysis by Hilborn et al (2008), priority should be given to two areas of research: (1) assessment of the abundance, densities and gonad yield/quality of urchins in non-accessible areas (e.g., deep waters, cryptic habitats, non-fished areas); and (2) spatially-explicit growth analysis to determine whether the urchins are recruiting to the fishery by growing to legal sizes or by influx of legal urchins to the fishing grounds, as well as to use as inputs in stock assessment models.

Collecting and analyzing the information suggested here will clear the path towards setting Total Allowable Catches (TACs). In scenarios of high quality and quantity of data on the resource and its fishery, stock assessment models may be developed to establish reference points. Then catch quotas can be allocated in order to achieve those target reference points. The stock assessment models explored by Hilborn et al (2008) for the San Diego sea urchin fishery could be updated once the identified data gaps are filled and expanded to other areas en California. Further, if spatially-explicit information on catches, effort, size frequency distributions of the catch and growth analyzes are available, more appropriate and robust size-structure statistical catch-at-age

models may be developed to assess the status of the sea urchin stock(s) in California and used to set annual TACs.

On the other hand, when information is not sufficient to be integrated in stock assessment models or when uncertainty around the available data does not justify such effort, a set of trigger levels or proxies for reference points based on the available information (usually limited to historical and current catch data) could be use to develop harvest strategies based on TACs. This approach will also identify additional data gaps and gathering protocols that would enable the fishery to move away from a data-limited situation and to design more informed harvest strategies that confers less risk in management regulations. In Southern California, the San Diego sea urchin data collection program is a key example of how to move from data-poor to data-rich conditions and a highly desirable alternative when there is a lack of historical information on the fishery and the status of the stocks.

1.0. General data requirements for monitoring and assessment of the California sea urchin fishery

Sea urchins, as others sedentary benthic organisms show a high degree of dependency with their substrate, with limited mobility throughout its life or adult stage (Aller et al. 2001). Movement capabilities and biological characteristics of sea urchins and the physical features of its environment may determine the spatial patterns of its distribution (Underwood and Fairweather

1989). Thus, variation in benthic habitat structure (either of biogenic or abiotic nature) generates heterogeneous distribution and abundance patterns. The amount of suitable habitat and available space to settle are important factors affecting their recruitment and survival, determining its population variability and spatial structure, which is usually persistent in time (Tilman and Kareiva 1997). Life history traits of sea urchins often show small scale variations associated with specific locations and environmental gradients. Growth, survival, fecundity and settlement may also show spatial variations along latitudinal gradients. However, growth of red sea urchin *Strongylocentrotus franciscanus* showed no significant relationship with latitude (from Alaska to Southern California) while survival decreased with latitude (Ebert et al. 1999). The latter could explain higher proportions of very large, old individuals in the southern vs. the northern part of the species range. Thus, local variations in growth and survival may be due to food quality and availability (Ebert al. al 1999) which are usually related with the complexity of the substrate (e.g. as a cover to predators; Caddy 2007). In addition, sea urchins show highly structured metapopulations with consistent differences in abundance, growth, gamete production, larval settlement and connectivity between areas. Thus, identifying metapopulations and the main sources and sinks of recruits is an important matter for management purposes.

The need for spatially complex biological information and metapopulation considerations are inversely related with the species mobility in different life stages. Thus, emphasis on spatial structure requires the need to identify appropriate spatial scales for data gathering, analysis and management of sea urchin populations. Further, the spatial complexity of the resource and its users is often an ascribing factor in making fisheries data-poor or data-limited. In some cases, a fair amount of data is available, although not in adequate quantities or at fine enough scale to reveal local patterns of abundance (Prince et al. 2008). Thus, given the high spatial and temporal variability in red sea urchin populations, collection of data useful for fishery and ecosystem management may require more resources than are typically available for agencies tasked with such management. In addition, data requirements for stock assessment are sometimes not related to stock size or value (i.e., some stocks may be too small to be worth monitoring by management agencies). In recent years, a possible solution to this problem has been to enlist fishery members in a cooperative data collection program. In this respect, Prince and Hilborn (2003) has proposed extensive use commercial fishermen as data collectors in order to gather enough information at appropriate scales to support fine-scale management. The San Diego Watermen's Association (SDWA) has developed a sampling protocol that allows working divers to collect random samples of sea urchin density, size distributions, environmental variables, etc., during the course of normal harvesting operations (Schroeter et al 2009). Although this information is extremely useful, additional information inside and outside the fishing grounds needs to be collected for stock assessment purposes. Hilborn et al. (2008) highlighted several data gaps that need to be addressed in order to reduce the uncertainty in stock status (Table 1) as well as identified the following weakness in the San Diego sea urchin assessment:

1. It appears that most recruitment comes from large individuals from an unknown population (e.g., deep waters, cryptic habitats, other sub-populations). Until the source population for the apparent recruitment of large individuals is identified any assessment will be unsatisfactory. Thus, the primary need is to obtain abundance samples from outside the fishing grounds, and to identify if there are large populations of cryptic individuals within the fishing grounds.

2. Another high priority would be area-specific estimates of sea urchin growth at relevant spatial and temporal scales to determine to what extent the productivity of the fishery is sustained by sea urchin grow to legal sizes (or sustained by unknown populations). In addition, the role of any factors such as kelp, temperature, sea urchin density, etc., in affecting growth rates need to be evaluated.

Table 1. Summary of data gaps identified by Hilborn et al. (2008) for the red sea urchin fishery in San Diego, CA.

Description
Number of RSU killed by quicklime 1966-1980(Pt Loma and La Jolla)
Quantify abundance of sub surface kelps (elk, palm)
Separate RSU harvests by kelp bed (i.e. 1,2,3,4 and North County)
Obtain average price of RSU for San Diego for 1988-2006 by month
Using CDFG log books and receipts obtain CPUE (catch per diver day)
Using CDFG log books obtain number of boats (La Jolla and Point. Loma over the threshold of over 20 landings or over 8000 lbs. in any year)
Literature regarding RSU abundance and size distribution in San Diego (Segars, Kelco, etc)
Develop assessment methodology using calibrated ROV surveys for deep water RSU.
Literature regarding bioenergetic parameters for sea urchin growth, mortality, and gonadal maturation

1.1. Fishery-dependent information

Fishery-dependent and independent information through surveys and monitoring programs should be expanded at appropriate spatial scales (e.g., consistent with the biological units or sub-stocks; Table 2). Although fishery-independent information is highly demanding in terms of human and economic resources, several improvements in the information recorded in mandatory log-books will improve and optimize the information available and help to depict biological patterns in the species and its fishery, as well as trends in catches and CPUE:

(i) Geo-referenced information with higher spatial coverage, and especially resolution (e.g, port-based), registered in mandatory log-books;

(ii) Designated port-based sampling of catches, registering:
   a. Size frequency distribution of the catch would be extremely beneficial for monitoring as well as for stock assessment purposes (see Section 2).
   b. Gonad yield and quality sampling

1.2. Fishery-independent information

Fishery-independent information should be gathered, when possible, at different spatial scales (as mentioned in Section 1.1.), within and outside the fishing grounds, and by (i) surveys conducted by the management agency; (ii) industry-funded surveys and data collection programs; and/or (iii) community-based (divers) data collection programs. Examples of directed research and data collection programs by agencies, industry and diver/fishermen already exists in the US, California, and for the sea urchins in particular. Expanding such efforts would be extremely beneficial to assess the status of the (sub-) stock(s) and to elaborate a robust long-term Management Plan for the California red sea urchin fishery.

A comprehensive list of dive/area/region specific (fishery –dependent and –independent) is provided in Table 2

Table 2. Site/area specific information to be used in monitoring and implementation of management strategies for the red sea urchin fishery. Tier corresponds to suggested level of priority. Note: Although information at the dive/site level will be extremely beneficial, it would require a proactive stakeholder's participation in gathering and sharing this information.

Type		Responsible			Location			Data	Specifications	Tier
Fish-dep	Surveys[a]	Divers	Processor	Agency	Sea	Port	Plant			
				**				Dive specifications	Date	1
			*	**					Latitude, longitude, depth	1
			*	**					Bottom time, area harvested/covered	1
				**				Yields	Catch (lbs or individuals)	1
			*	**					CPUE (per time; per area)	1
				**					Estimate of urchins left behind	2
				**				Biological	Density (ind/m^2; lbs/m^2)	1
				**					Size frequency distributions (mean, min)	1
				**					Proportion of legal urchins	1
				**					Gonad quality and yield	1
				**					Recruitment areas (estimates)	2
				**					Recruitment (ind/m^2)	2
				**					High densities areas (overgrazing)	2
				**					Community composition (other species)	2
				**				Environmental	Sea surface temperature	2
				**					Bottom type (sand, reef, ledges, etc)	2
				**					Algae coverage (%) and type (e.g, macro)	2

[a]Surveys should be conducted insinde and outside the fishing grounds

*This information can be shared with the processor to optimize information transfer (confidentiality issues may arise)

**Some info may be included in log-books but most requires surveys (subject to economic and human resources availability)

In addition, a series of surveys or dedicated research/experimental programs should be considered (Table 3). Among these, reducing the uncertainty in growth estimates, identifying the "stock unit", and estimating the sea urchin population outside the fishing grounds should be given maximum priority.

Table 3. Potential dedicated research programs and/or surveys for the red sea urchin populations in California.

	Data	Research/Survey*	Frequency	Use/Purpose
1	Growth and mortality rates	Area-based growth and mortality analyses	Multiple	Input in stock assessments
2	Recruitment and settlement surveys/experiments	Transects or scrub brushes	Annual	Determine areas of high recruitment; input in stock assessment
3	Kelp biomass estimates (canopy and understory)	Transects/quadrats	Annual	Input in stock assessment
4	Deep water sea urchin assessments	Transects by means of ROVs or baited traps	Multiple	Input in stock assessment
5	Movement	baiting experiments or tagging (mark-recapture)	Once	Determination of unit stock; input in stock assessment
6	Cascading effects of urchins removals	Area closures to fishery (urchins and predators)	Ongoing	Ecosystem-based approaches; Certification
7	Larval studies in a meta-population context	Hydrodynamic models; larval durations	Ongoing	Unit stock; input in stock assessment; Certification
8	Effects of diet on gonad quality/yield (lab)	Laboratory experiments with different diets	Once	Improved quality; optimal harvest

*this is not a comprehensive list of reseach/sampling methods

1. Growth and survival estimates need to be addressed at the appropriate spatial scales and under different conditions of algae type and biomass (e.g., inside and outside the kelp bed, under different conditions of drift algae, etc.). Several studies of growth and survival have been performed in the last 2 decades along the whole range of spatial distribution of *S. franciscanus* (Ebert and Russel 1992; Ebert et al. 1999). However, growth rates extracted from the literature differ significantly among locations and among studies within locations. A thorough literature review may highlight some patterns in growth as well as the most appropriate methodology to use.

2. The ongoing recruitment experiments could be expanded to other areas identified as source of larvae and settles. In addition, fishermen input may be used in order to get information about areas of high recruitment. At the moment, divers participating in the San Diego data collection program qualitatively register areas of high recruitment within their sampling protocols. This could be intensified in order to get quantitative estimates: once areas of high recruitment are identified, a few transects may be set in order to count and measure all recruits. This, once calibrated, could be a cost-effective methodology to gain insight on spatial and temporal intensity in recruitment.

3. Although different techniques (e.g., aerial photographs, remote sensing, etc.) to assess kelp bed coverage and biomass exist, these are usually costly and time consuming. Considering that the spatial coverage of individual dives is such that effectively most parts of the kelp bed are intensively harvested, additional data gathering and simple analyses could be done by divers in the fishing area. For example, sonar and visual estimates of canopy coverage could be use to estimate relative abundance of subtidal kelp. These estimates should be calibrated by means of more accurate techniques and corrected by tides and current conditions when possible.

4. Ideally, movement rates should be estimated for different areas and different conditions, such as availability of kelp (both stipes and drift biomass), habitat rugosity, and sea urchins density.

5. Long-term area closures can be extremely useful in determining sea urchin dynamics under no-exploitation conditions. Selection of this no-fishing areas should be carefully chosen to consider the whole spectrum of environmental conditions affecting sea urchins and kelp beds when possible (e.g., habitat complexity, depths, currents, etc).

The information shown in this Section is crucial in developing management and harvest strategies for the red sea urchin fishery in California, either based on formal statistical stock assessments or on empirical reference points (see section 2.0). However, all the information mentioned here relates mostly with biological sustainability issues, and economic analyzes would need additional information to be gathered (not covered in this report).

2.0. Reference points, harvest strategies and TACs for the California red sea urchin fishery

A variety of regulatory approaches are available for invertebrate fisheries and sea urchins specifically, each with particular needs for scientific information based on the characteristics of the resource and its fishery. In the long term, sustainable management has to involve an adaptive process of regular information gathering, reassessment of stock status, and adjustment of harvest policy. Direct management methods for estimating and regulating the exploitation rate includes size limits as one of the simplest regulatory measures, and often the first to be applied as in the California sea urchin fishery. Size limits usually refer to a minimum harvestable size but may also include a maximum harvestable size. These direct methods minimize or eliminate reliance on biomass point estimates but require different regulatory tactics and different types of assessment data. After direct methods, it has often been assumed that assessment support for regulatory actions should be aimed towards producing an annual estimate of harvestable stock size, from which a total allowable catch (TAC) or quota can be derived by multiplying the stock estimate by a target fishing mortality or exploitation rate. However, this approach may yield errors in annual biomass estimates and presents high costs associated with data gathering and analyses. Figure 1 shows these different management approaches and the basic distinction between direct regulations of exploitation rates and TAC/quota management. The biomass estimation required for setting TACs can proceed by direct surveys, by fitting stock assessment models to relative indices of abundance (e.g., CPUE), and/or by performing localized depletion fishing experiments to provide density estimates that can be extrapolated over larger areas.

A harvest strategy specifies the management actions necessary to achieve defined resource objectives in a given fishery. Specifically, a harvest strategy should specify a process for monitoring and conducting assessments of the biological and economic conditions of the fishery as well as harvest control rules or decision rules that control the intensity of fishing activity according to the its biological and economic conditions. Determining appropriate exploitation levels for marine resources, through implementation of harvest strategies, is often conducted via estimation of performance indicators, such as the current stock biomass (B) or the fishing mortality rate (F). These indicators, usually estimated via statistical stock assessment methods, are compared with biological reference points, such as the biomass that achieves maximum sustainable yield (MSY; B_{MSY}) or the fishing mortality that achieves MSY (F_{MSY}). The three most common harvest strategies are (a) fixed exploitation rate, in which the objective is to take a constant fraction of the stock each year (e.g., $F_{35\%}$); (b) constant catch, in which the goal is to keep the catch uniform over the years independently of the stock size; and (c) constant escapement, where the goal is to maintain the spawning stock size near some constant level.

The TAC-setting process usually follows a regular annual cycle, where data are collected and databases updated (e.g, with catch, age and size composition, survey biomass). These data are used as inputs in stock assessment models to calculate estimates of population parameters, biomass, and age structure. The processes of stock assessment and harvest strategy development are interrelated. Stock assessment models are used in setting the reference points and consequently in the development of the harvest strategy, and the current biomass-based harvest strategy uses the most recent biomass estimates in determining a TAC (or Acceptable Biological Catch: ABC) (Section 2.1; Figure 2a).

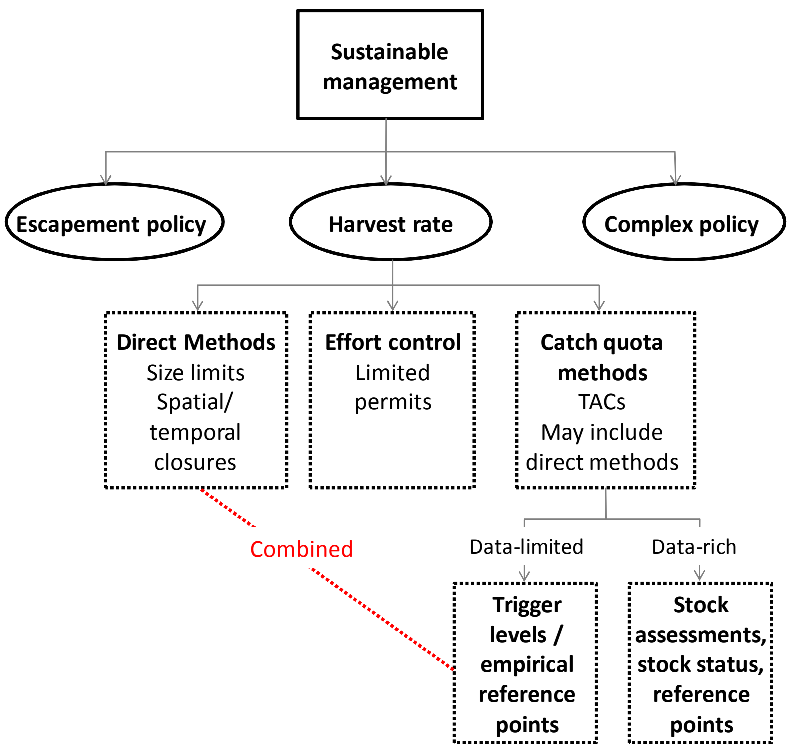

Figure 1. Harvest strategies mechanisms under data-limited and data-rich situations to achieve sustainable management

Thus, stock assessment models are used to integrate the scientific information, except when information is not sufficient to construct such a model or when the uncertainty around the available data does not justify such effort. Although there are exceptions, this is the case for most small-scale fisheries where there is not a formal assessment process and where biomass estimates are simply not available. In the absence of biomass estimates, and hence biomass-based target and limit reference points, conservative trigger levels may be identified as proxies for these reference points based on the available information (usually limited to historical catch data) and thus used in setting TACs (Dowling et al. 2008; O'Neill et al. 2010; Reuters et al. 2010; Section 2.2; Figure 2b).

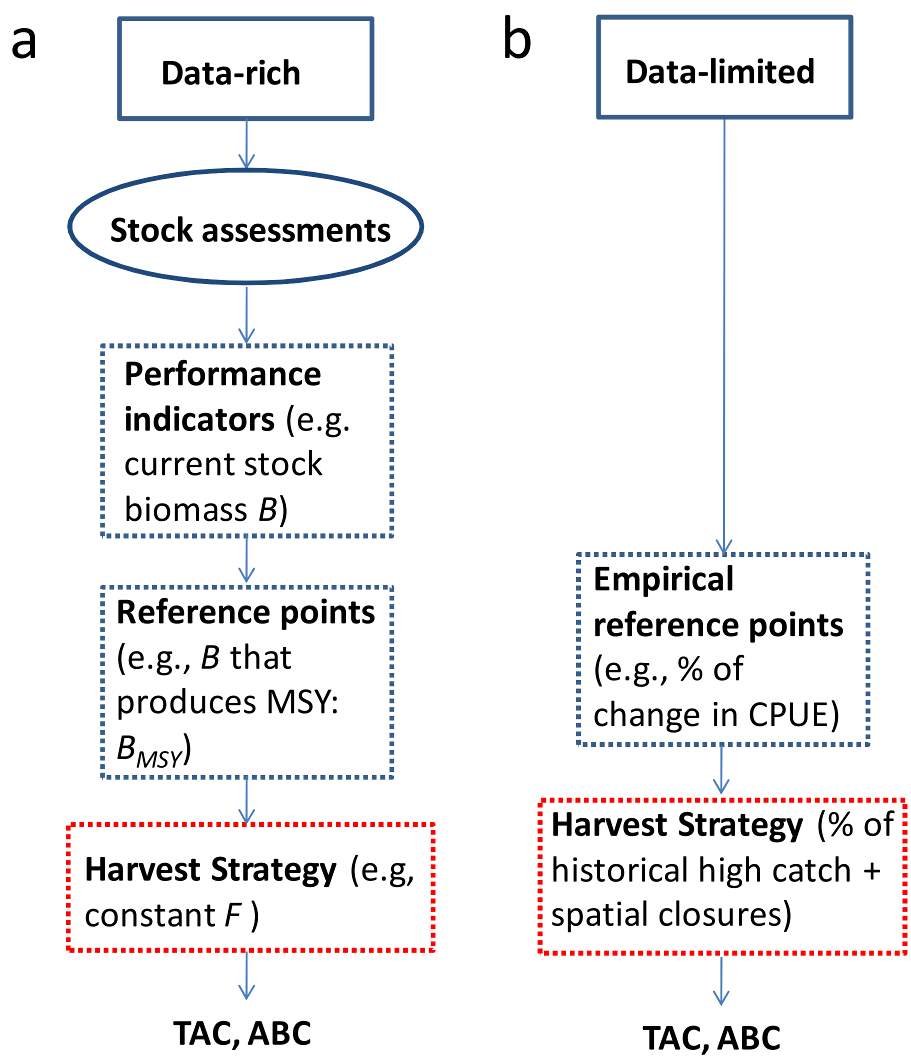

Figure 2. Flowchart indicating the technical process for developing a harvest strategy and implementing TACs or ABCs by (a) integrating all the available information in stock assessments to generate limit and target reference points; and (b) using the data available directly to generate proxies for reference points ("trigger levels").

2.1 Using statistical stock assessments to determine the status of the stock (performance indicators), reference points and harvest strategies

2.1.1 Background on sea urchin stock assessment in California: The Pt. Loma sea urchin fishery

Evaluations of the red sea urchin populations in California have been scarce, with a few exceptions including the stock assessment for the San Diego fishery (Hilborn et al 2008). In this study, all available data were used to assess the current stock size and potential productivity in the Pt. Loma kelp bed and to determine trends in abundance. Information available included catch and effort data, extensive length frequency and density estimates from the community-based data collection program. The high spatial and temporal resolution of the available information helped to discern patterns in fishing effort, proportion of legal sea urchins, and estimates of the total abundance of sea urchin in the study area, although a lack of a long term data series on abundance estimates and other biological information precluded some analyses on the status of the stock per se. Further, as this was the first assessment for sea urchins in this area, a range of assessment tools were explored, rather than selecting an individual assessment model. In addition, several major issues associated with the dynamics and biology of sea urchins in Pt. Loma, but common to other areas in California, were considered in the assessment methodologies:

(i) Given the long life and slow growth of urchins, questions remain as to whether the current fishery is based on a sustainable balance of recruitment and fishing mortality, or possibly the fishery is still "mining" a large population (mainly from non-accessible areas) and current yields are not sustainable. Length frequency data in Pt. Loma showed a high frequency of large urchins, a length frequency that is inconsistent with a high fishing mortality rate of individuals recruiting to the commercial fishery at the legal size limit.

(ii) Even though scientists and commercial divers recognize a great deal of spatial structure within the area with respect to the physical structure of the bottom, kelp coverage, urchin density, and the proportion of urchins that have commercial quantities of uni, the stock assessment models assumed an homogeneous stock within the area modeled given the quite small fished area in Pt. Loma.

(iii) An important assessment issue was the relative abundance of "recruited" or "good uni" and "non-recruited" or "bad uni" individuals. Non-recruited urchins due to non-accessibility (i.e., deep water, crevices) and the potential correlation between good temporal and spatial conditions in kelp abundance with greater proportion of the total urchin population to have commercial quantities of uni were also addressed within the different assessment models.

Pt. Loma sea urchins assessments were considered data-limited. Time series of landings and logbook CPUE, treated as an index of abundance, were available but not a time series of length frequency data. In addition, CPUE could be not proportional to abundance due to the searching behavior of fishermen (e.g., hyperstability). The different approaches taken were: (1) a model free analysis in trends in surplus production using CPUE as an index (not necessarily a linear one) of abundance; (2) a simple delay-difference model that tracks the numbers of urchins with and without uni; (3) an age structured model that allows kelp to determine the relative maturity and harvest of the urchins; and (4) analysis of recent length frequency data to see what information can be extracted on the exploitation rate and size of recruitment from the LF data in recent years.

All four assessment approaches supported the hypothesis that there were no major sustainability concerns for the Pt. Loma stock at its current level of exploitation and productivity. The trend in CPUE suggested stable populations in recent years, and the length frequency data were most consistent with reasonably low fishing pressure. However, none of the models used were completely satisfactory mostly due to obvious limitations in the data available:

(i) This study explored the use of CPUE and divers perception of changes, but recognized that neither of these provided an estimated of the true trend in abundance. Neither approach seemed likely to reconstruct any index that truly represented changes in abundance, even within the commercially fished areas of the Pt. Loma kelp bed. Uncertainty about trends in abundance of unfished areas must therefore be even greater.

(ii) Density estimates from the community-based data collection program were constrained by their close connection to decisions about where to dive, thus were non-random samples, and were also limited by the number of individuals involved in the program. The absolute number of samples was not necessarily limiting, but obtaining a more even coverage over all of Pt. Loma would have improved confidence in the data.

(iii) Historical kelp abundance data was not satisfactory. Inter-annual pattern of abundance and the spatial pattern may both be important since scientists and divers continue to believe that kelp is a key driver in sea urchin recruitment and uni production.

In summary, as stated before, the two major unknowns about basic stock biology identified where: (1) is there a large proportion of the population not vulnerable to harvesting because either they are in crevasses or in deep water or do not have any uni, and (2) does recruitment of small urchins come from the local stock, or from larval drift from outside the Pt. Loma area.

2.1.2. Potential approaches for stock assessment of the red sea urchin in California

The assessments described in Section 2.1.1 could be replicated to other areas in California, as well as extended into a state wide assessment with the obvious caveats of the effect of spatial structure in life history traits (i.e., growth, mortality, recruitment) in determining the overall reproductive capacity of the stock(s). <u>However, updating these models would imply to obtain abundance samples from outside the fishing grounds, and to identify if there are large populations of cryptic individuals within the fishing grounds.</u> An important benefit would be to support and expand the community-based data collection program to other areas in California or to implement directed surveys to non-fished areas as the highest priority. If closed areas are set up within what are now normally fished grounds, then the abundance and size distribution in the closed areas would need to be monitored as well. <u>Additionally, growth studies need to be performed at appropriate spatial scales to determine spatial patterns in growth and how these spatial patterns relate to several factors such as kelp biomass, sea temperature, sea urchin density, etc.</u>

A more appropriate approach would be the use of <u>statistical size-structured models</u> as have been used worldwide to assess the stock of different marine invertebrates (e.g., green sea urchins in Maine: Chen et al. 2003; Grabowski and Chen 2004; Kanaiwa et al. 2005; lobsters in Maine: Chen et al. 2005 and Australia: Punt and Kennedy 1997; Hobday and Punt 2001; lobsters and abalone in New Zealand: Breen et al. 2003; Breen et al. 2006; lobster in South Africa: Bergh and Johnston 1992; Johnston and Butterworth 2005; and crabs in Alaska: Zheng et al. 1995). Size-structured population dynamics models are appropriate for sea urchin populations since these organisms are difficult to age and growth is highly variable among individuals. Growth transition matrices should be constructed based on available information from the mentioned analyses and published studies (see Ebert and Russel 1992; Ebert et al. 1999; Woodby1999) and the recruitment component can be a function of a particular environmental time series (e.g., kelp biomass estimates). The size-structured model is then fitted to an index of abundance (e.g., CPUE), catch data and length-frequency distributions of the catch/population.

Size-structured model analyses could be conducted separately for different areas/zones in California, according to the spatial patterns of life history traits and growth in particular and matching biological units. Lastly, given the limited data situation, sea urchin stock status estimation should be conducted within a Bayesian approach to incorporate the uncertainty related to the scarcity of information available and in the sea urchin population dynamics (Punt and Hilborn 1997).

These models are often less data demanding than other stock assessment methods (e.g., age-structured). Minimum data requirements are:

(i) Commercial catch and effort data that could be obtained either from the log-books or from port-based samples.
(ii) Size or length-frequency data derived: a) from catch samples taken onboard by trained divers (e.g., community-based data collection program in San Diego), during port-based samplings or at the processing plants (if appropriately identified and geo-referenced); and/or from directed surveys or research programs.
(iii) Spatially-explicit estimates of growth parameters.

All these data requirements have been described in Tables 1 and 2

Thus, as a more complete temporal and spatial coverage of length frequency data and growth estimates gets accessible, it would be possible to apply a statistical size-transition model to the sea urchin populations in California. However, it would be far from satisfactory if the assessment suggests most fishery recruitment comes from large individuals from an unknown population as it seems to be the case for Pt. Loma, San Diego.

2.1.3 Setting reference points, harvest strategies and TACs

Certainly, it seems very useful to update and expand the models used by Hilborn et al. (2008), or to implement a statistical size-transition model as soon as specific growth data and estimates of abundance outside fished areas become available. Such an analysis would be required to try to reconstruct the history of the fishery and to estimate the status of the stock by means of performance indicators (e.g., B_{current}, B/B_0). Harvest strategies and their respective TACs will be then set based on the status of the stock relative to a particular reference points (Figure 1b). Most commonly used biological limit and target reference points for North American sea urchin fisheries have been summarized in Botsford et al. (2004).

These modeling efforts could imply extensive efforts of data collection and high levels of human and economic resources. While it would be possible to build a spatially-structured model for the California sea urchin that attempts to capture the species dynamics, another question is whether such a complex assessment would be necessary for sustainable management or worth the financial expense. As has been shown in the San Diego sea urchin fishery and many others sedentary resource fisheries in Australia and Japan, community-based data collection programs (Schroeter et al. 2009) are a cost-effective way to gather fine scale spatial and temporal information. The value of these programs could be greatly enhanced by extending such protocols to areas outside the fishing ground (Schroeter et al. 2009).

2.2 Developing harvest strategies by using trigger levels as proxies for reference points in data-limited situations

As described in Section 2.1, for most data rich and high gross value production (GVP) fisheries such as large-scale industrial fisheries, harvest strategies and respective catch quotas (e.g., TACs) are based on biomass reference points, but biomass estimates are not always available or reliable enough to be used in setting such reference points and consequent catches to achieve those target reference points. This is mostly the case, although not exclusively, for small-scale fisheries. Moreover, for some of these fisheries, the concept of an equilibrium biomass is problematic due to large variability in stock abundance. An additional problem is mismatch of scales, where cost and logistics prevent adequate data collection for the construction of quantitative assessments at small scales appropriate for the population dynamics and life history of the targeted populations.

When model-based fishery assessment approaches are not available, an alternative approach to setting catch quotas and developing harvest strategies may include adapting general management tools such as catch and effort limits, gear restrictions, and spatial controls under a precautionary set of decision rules. These harvest strategies need to be easy to understand by all stakeholders, as well as precautionary, pragmatic (given the economic and biological data limitations), and cost-effective (Campbell et al. 2007; Dowling et al 2008). <u>A potential approach could combine empirical reference points or trigger response levels (often based on historical catch levels) with decision rules that aimed to improve the knowledge of the fishery by first collecting biological data and hence provide a basis to further develop the harvest strategies using more sophisticated assessments in the future</u> (Brooks et al 2010; O'Neill et al. 2010). If possible, these harvest strategies need to consistent to the reference points, in which an extreme case could be a simply "best guess" proxy suggesting little knowledge of their relative magnitude with respect to the biomass thresholds to which they were intended to correspond.

Thus, in the absence of biomass estimates, and hence biomass-based target and limit reference points, conservative trigger level proxies may be identified as reference points based on the available information (e.g., historical catch data, CPUE, mean sizes of the catch, etc.). Possible triggers may include: (i) changes in averages or trends in CPUE (e.g., X% of change in CPUE from the long-term average; Figure 3); (ii) changes in spatial fishing patters (especially to detect serial depletion processes); (iii) changes in species composition (due to the relevant role of the species within its ecosystem; e.g., changes in barren areas); (iv) changes in mean and maximum caught urchin sizes; or a combination thereof. Given the small scale spatial structure of the sea urchin populations and the likely metapopulation structure within Californian waters, these triggers should be area- or zone-specific (e.g., by kelp beds if doable). Additionally, each trigger should involve different response levels such that progressively higher data and analysis requirements are assigned to higher response levels to minimize the risk of overfishing associated with further fishery expansion. If a response level is reached, then the status for a particular species will be re-assessed with a possible revision to the amount of allowable harvesting.

The described approach for developing harvest strategies in data-limited fisheries should be part of iterative process involving discussions among scientists, fishery managers and stakeholders Further, it should not only be precautionary to accommodate any uncertainties but also be directed towards more informed harvest strategies once fisheries further develop. For this purpose, different response levels may be set for any trigger, with an increasingly need for information and detailed assessment to be undertaken at each of those levels (Figure 3). Sainsbury et al. (2007) and Dowling et al. (2008) applied this framework in several data-poor fisheries in Australia and identified 3 trigger levels (cited here as examples to clarify this framework):

1) Level 1 should be conservative (e.g., half its historical high catch) and may represent an early indicator of a given change in the dynamics of the fishery that deserves clarification from either a management, economic or sustainability point of view (e.g., what factors are responsible for consistently lower catches). Examples of this level of trigger may include fisheries with low harvest rates and low catch volumes, in which case the fishery is unlikely to have funds available to support detailed assessments. However, low-cost exploratory analysis such as spatial and temporal CPUE trends or size frequencies of the catches should be performed and causes of changes discussed at all levels of management (i.e., divers, managers, scientists). If a reasonable justification for the observed changes can be made that does not relate to potential overfishing (e.g., catches have decreased because of a change in market demand as opposed to decreased availability), then the fishery may continue with no immediate management intervention. On the contrary, in the absence of any other

explanation, a precautionary management response such as spatial (or temporal) closures may be implemented, as well as a revision of the subsequent response level values of the trigger.

2) Level 2 should be set at a value intended to correspond to a level of exploitation that deserves a more informed and robust evaluation of stock status. This level is still intended to be conservative, although a more formal stock assessment should be undertaken on the species to justified increasing existing response level values.

3) Level 3 may be considered a proxy for a limit reference point (LRP) after which all fishing pressure on the species must finish and no further increase in catch or effort should be allowed pending expert consultation and more detailed or sophisticated stock assessments.

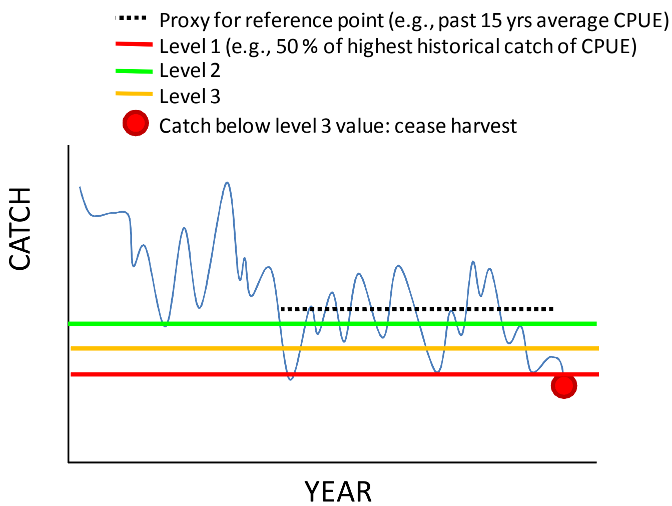

Figure 3. Schematic representation of a trigger or proxy for reference point (i.e., changes in current catch with respect to the previous 15 years average or values with respect to historical high catches) with 3 different levels: (i) level 1 (most conservative) corresponding to a value equal to 50% of the historical high annual catch. Going below this point will need at least an explanation on whether changes reflect issues others than overfishing; (ii) level 2, where going below this value will require availability and analyses of relevant information and assessment of the stocks; (iii) level 3, where current catches below this level will imply a cease of the fishing activity until further stock assessments or expert consultation.

Clearly, there is a trade-off between setting conservative trigger levels or proxy reference points in the face of uncertainty against the cost associated with collecting more information that would allow higher catches (through less conservative levels to be set for those proxy reference points), thus optimizing industry profitability

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