<u>**PROPOSAL NARRATIVE**</u>

1) Background and Rationale

We propose to demonstrate that sea urchin aquaculture, specifically gonad enhancement (bulking), can be done with captured and cultured urchins held at high densities and fed cultured and harvested seaweed. This will be done to increase product value and marketing options for aquaculturists and fishermen. The proposal addresses technological, regulatory and socio-economic barriers to sea urchin and seaweed aquaculture development, as applied in the Gulf of Maine but applicable to other regions where seaweed and sea urchin fisheries co-exist, such as southern New England, California, and the Pacific Northwest. The project is also about finding ways to make urchin and seaweed culture more compatible with capture fisheries and fisheries management. If culture husbandry can be integrated into and used by capture fisheries to add value and sustainability, then the economic value of both aquaculture and harvest fisheries can be increased. If fishermen and processors can gain more flexibility and marketing opportunities using aquaculture tools, then this will help create stable and reliable employment.

Status of the sea urchin market and fishery

Sea urchin gonads are a culinary delicacy prized in many European countries, Chile, North America, Asia, and especially Japan, which accounts for around 90% of worldwide demand. Urchin gonads are known as uni in Japan, and historically they were available only to the wealthy, but the rise of an affluent middle class there led to wider consumption. The resulting fishing pressure caused the collapse of native Japanese stocks, and demand is now largely met from other urchin fisheries worldwide (Yokota, 2002).

Throughout the 1990s, the U.S was a major supplier of high-quality fresh urchins to Japan, with California and Maine contributing over 2/3 of the total imported supply (Reynolds and Wilen, 2000). The green sea urchin *Strongylocentrotus droebachiensis* from the Gulf of Maine is one of the more highly valued of the imported species. Daily Japanese auction prices for green urchin uni of US East Coast origin fluctuate, ranging in 2012 from $20 to $110 per kg ($44-$242 per lb). (http://www.fis.com/or http://swr.nmfs.noaa.gov/fmd/sunee/jmn.htm). Prices for the red sea urchin *S. franciscanus*, the commercially important US West Coast species, while not quite as high ($40 to $70 per kg), are nonetheless of significant value to those involved in the fishery. Although dock prices for urchins ($1 to $5 per lb) are much lower than auction prices for processed uni, they have supported lucrative fisheries on both coasts of the US since the early 1990's (Wilen and Wessells, 1997). However, since that time catches of both the red urchin from California and the green urchin from Maine have declined. In California, stock declines have been attributed to a combination of overfishing, predation by sea otters, and el Niño effects (Kalvass and Rogers-Bennet, 2002; Kalvass and Hendrix, 1997). The total catch in California peaked in 1988 at around 52 million lbs before declining and stabilizing at around 10,000 million lbs in recent years. The fishery is now considered to be fully exploited and likely overfished in some regions (Kalvass and Rogers-Bennet, 2002). In Maine, the fishery peaked in the mid 1990's at a harvest level of about 40 million lbs, with a dock value of over $30 million. During this period around 1,500 divers were harvesting the stocks with minimal regulatory restriction. Stocks began to decline in the late 1990's and the fishery is now greatly diminished. According to the Maine Department of Marine Resources (DMR), in 2011 2.3 million lbs were landed with a value of $4.6 million ($2.02/lb). In Washington State, the near collapse of the red urchin fishery led to the closure of major processing facilities, contributing to underutilization of the resource (Ulrich, 2012). This is a cautionary tale for the fisheries in Maine and California, which remain commercially viable.

Regulatory management and industry challenges

Regulation of the sea urchin fishery in Maine is a collaborative effort between the Maine DMR and the Sea Urchin Zone Council (SUZC). The SUZC consists of 15 members, seven elected from the industry and eight appointed by the Maine DMR commissioner. If possible, two of the appointees include a marine scientist and an aquaculturist. The Maine DMR and the SUZC hold regular meetings to discuss research projects, regulations, and management issues. The DMR proposes regulatory changes at these meetings, and the SUZC provides feedback and suggestions for how proposals might be modified or implemented. The SUZC meetings are attended by fishermen, who frequently voice opinions regarding the fishery and management decisions. It is fair to state that a great deal of frank and sometimes heated discussion occurs at these meetings.

Over the past 10 years the Maine DMR has adopted increasingly stringent regulations in an attempt to rebuild wild stocks. Harvesting methods are limited to diving, raking, trapping and dragging, although the majority of the catch is taken either by divers or draggers. Management is done on a zone basis within two areas covering roughly the southern (Zone 1) and northern (Zone 2) halves of the Maine coastline. As of 2011 the fishery in Zone 1 had 49 licensed divers and 17 draggers, and the Zone 2 fishery had 156 divers and 154 draggers. The fishery is currently closed to new entrants. Size restrictions impose limits on the minimum (52mm) and maximum (76mm) test diameter (TD) of harvested urchins. Legal fishing days are determined in advance of the season, and are limited to specific days in each of the two Zones, with harvesters selecting either "early" or "late" days during Sept. through Mar.

It is clear that the urchin fishery in Maine faces many challenges. Dive surveys and port sampling conducted by the Maine DMR from 2007 through 2012 indicate that stocks are not recovering, and further catch restrictions have been proposed for Zone 2 for the 2012-13 season (SUZC Meeting Minutes, 3/29/12). Diminished supply from the Maine fishery has caused some of the larger processing companies to turn to other sources, including eastern Canada and Chile. Decreased supply and lower quality for Maine processors could ultimately lead to their exit from the industry, further undermining the economic viability of the fishery, as has happened in Washington State (Ulrich, 2012). Anecdotal evidence (Atchan Tamaki, I.S.F. Trading) and empirical data collected from Maine DMR port sampling indicates that average gonad yields have declined from 15-18% to around 10% gonad somatic index (GSI). (SUZC Meeting Minutes; http://www.maine.gov/dmr/council/sea_urchin/minutes/2012jan5.pdf). The reasons for this decline are unknown, but may be due to harvesting methods. Lower gonad yields result in decreased value to the fishery. Adding to quality issues is the fact that the Maine harvest season runs from Sept. through Mar. to take advantage of Japanese market conditions and to meet the demands of processors for supply. However, urchins harvested in September and in March are often not at peak quality, as they are either too early into the natural gametogenic cycle (September) or have begun spawning (March) (Walker and Lesser, 1998; Walker et al, 2001). In addition, the Obon Holiday, similar to our Memorial Day, is one of three Japanese holidays when uni demand and price increases, but it occurs in mid August when the GOM fishery is closed.

The current regulatory and marketing scheme results in an all or nothing harvesting approach that encourages divers to focus on quantity over quality. In large part this can be attributed to the fact that management of the fishery has evolved to rely on limited, pre-determined fishing days as a management tool. To maximize income many harvesters feel pressured to capture as many urchins as possible on each fishing day, sometimes diving under dangerous weather conditions to do so. Harvesting techniques that promote conservation and sustainability, such as hand harvesting and culling undersize or oversize urchins on bottom, are more deliberative and time consuming. Some harvesters instead resort to raking and culling on the boat, which may be anchored some distance away over less productive habitat. This can mean that for every ten boxes of legal urchins, four boxes are dumped overboard as cull, likely with low survival (Hunter, 2012). Further, marketing options are limited as harvesters need to sell their catch immediately upon harvest, with less control over quality and market timing. This results in less value all the way through the supply chain from harvester to processor.

Industry stakeholders are concerned that the economic viability of the fishery is threatened by declining yields and quality, and there has been discussion at SUZC meetings about modifying the management strategy, for example by moving to a catch quota or share system. A Fisheries Management Plan (FMP) is also currently being developed for the fishery. The proposed project may demonstrate a way forward, and it comes at an opportune time to participate in the drafting of the FMP. The State of Maryland's FMP for oysters includes oyster aquaculture as part of the fishery (Butowski et al, 2010), and we propose to examine if a similar approach is viable for the urchin fishery in Maine. Urchin gonad bulking provides a rationale and opportunity to motivate harvesters to adopt more sustainable fishing methods. To be viable, bulking requires that urchins be hand harvested and culled on bottom to minimize spine damage and mortality. Harvesters may be willing to adopt more deliberative capture methods if they can realize an economic gain, and this could reduce negative impacts to the resource. Harvesting during March when urchins are spawning has negative implications for the resource and the quality of the product, but it is done now to keep processors operating. If urchin bulking is adopted by the industry on a large enough scale, then the fishing season could be altered to account for resource conservation without creating supply problems. For example, the season could be ended in February to avoid the start of spawning, with urchins captured in Feb. held in bulking systems until March. Alternatively, the industry could do some harvesting in the summer months after urchins have completed spawning, and hold them in bulking systems for sale later in the year. If successful, the project will demonstrate how the fishery can increase sustainability, quality and value by using bulking and other aquaculture methods.

Sea urchin aquaculture

The high value of urchins, strong demand, and dwindling supply from capture fisheries has spurred interest in sea urchin aquaculture, or echiniculture (Hagen, 1996; Robinson, 2004; McBride, 2005). Echiniculture can strengthen the traditional fishery by ensuring a consistent supply, providing seed for restocking, relieving pressure on the natural resource, and delivering a quality product. Worldwide, there has been enough confidence in the viability of echiniculture to motivate serious research effort and commercialization of hatcheries, feed manufacture, and grow-out operations (Grossjean *et al*, 2001; McBride, 2005; Cook and Kelly, 2007). Strategies considered for grow-out include sea-based cage systems, sea ranching, and land-based tank systems. In Maine, echiniculture research efforts began in the late 1990's as wild stocks began to decline (Devin et al, 2004; Harris et al., 2000; Harris et al., 2003; Harris et al., 2004). In 2004, the University of Maine's Center for Cooperative Aquaculture Research (CCAR) located in Franklin, Maine joined these efforts, testing methods for nursery systems (Kirchhoff et al, 2008), establishing facilities for brood stock conditioning and hatchery production (Kirchhoff et al, 2010), and conducting feed trials (Eddy et al, 2012). In 2009 the CCAR was funded through the Northeastern Regional Aquaculture Center (NRAC) for a three year project to test land and sea based methods for growing urchins to market size. Three lease sites in the Gulf of Maine have each been seeded with 10,000 hatchery urchins and the results to date indicate that the seeded urchins have survived for two years at the release sites (unpublished data). Another 10,000 hatchery urchins are currently growing in a land based system at the CCAR in V-shaped raceways. Survival has exceeded 95% and many of these urchins are nearing market size after

2.5 years of growth (Fraungruber et al, 2012), and will be available for the proposed project. An economic analysis at the end of the NRAC project in August of 2012 will examine the cost/benefit of land vs. sea culture methods. As a direct offshoot of these activities, two shellfish growers (Maine Cultured Mussels, Inc. and Wildcat Oyster) are now pursuing aquaculture leases to grow urchins on bottom and in tanks, using seed produced at the CCAR hatchery.

To realize full value from these efforts further work still needs to be done on: 1) Identifying methods that ensure aquacultured urchins produce high quality gonads; 2) Validating consumer acceptance of aquacultured urchins and 3) Maximizing market value and identifying existing and new markets for aquacultured urchins (market study). The proposed project leverages prior funding and effort to help address these gaps.

Uni quality and enhancement

Good tasting uni has a light, briny flavor and a sweet aftertaste. The texture should be relatively firm (not mushy or oozing), and it should hold its' shape when picked up with chopsticks, but be soft and melting on the palate. Uni should never taste bitter or sour. Uni has historically been graded into three categories based on color, texture, and freshness. The higher the grade, the higher the price, and high grade uni taken directly from a living sea urchin commands the best price. The price differential between high and low grade uni can exceed 90% (Unuma, 2002). Gonad yield, or gonadal somatic index (GSI) is another important factor, as it affects processing efficiency and gonad size. Yields below 7% are not worth processing, and the optimum range is 12 to 25% yield (Unuma, 2002).

At the dock buyers assess gonad yield, texture and color to determine the price they pay to the fisherman. Gonad condition of *S. droebachiensis* varies by season and location and is dependent upon feed availability and quality, and the reproductive stage of the gametes (Vadas et al 1989; Vadas et al 1999; Walker et al 1998). The best quality uni is when nutritive phagocytes (NPs), which supply nutrients to the developing gametes, predominate in the gonads. In the Gulf of Maine (GOM) this occurs through the fall and winter months (Sept.-Mar.) when the fishery is open, but the best quality urchins are only available during a small window of 2-3 months. Green urchins begin spawning in March and their market quality deteriorates as the NPs shrink in size and the gonads become soft and runny. Spawning urchins can also taste bitter (Murata and Sata, 2000). Post-spawned (depleted) urchins re-build their gonads during the summer months as they feed on macro-algae. Nutrients required for gametogenesis (proteins, lipids, and glycogen) are stored in the NPs, which increase in size through the summer (Unuma, 2002).

Efforts to improve urchin gonads with diet or environment began in Japan over 40 years ago (Unuma, 2002). In the past 20 years researchers have done enhancement studies on a number of edible urchin species worldwide, and *S. droebachiensis* has been the focus of many of these studies due to its' high market value and wide distribution. It is well documented that urchins respond to increased food quantity or quality with increased gonad production (Russell 1998; Lawrence et al. 2001; Spirlet 2001; Schlosser et al. 2005). Macro algae is usually used as the primary diet, or as the control diet when formulated feeds are tested (Meidel and Scheibling, 1999; McBride et al., 2004). Formulated feeds can outperform seaweed in promoting fast somatic growth, and are preferred for use in aquaculture (Lawrence et al, 2001; Spirlet et, 2001; Lawrence and Lawrence, 2004; Eddy et al, 2012). Prepared diets can also produce larger gonads due to their higher protein levels (Carcamo, 2004; James et al, 2004; Schlosser et al, 2005). However, protein levels that are too high or have the wrong amino acid composition can yield bitter tasting gonads (de Jong-Westman et al., 1995; Böttger et al., 2006; Phillips et al, 2010). High protein formulated diets that promote somatic growth of juvenile urchins in land based systems can result in large gonads with poor color and flavor attributes (Böttger et al, 2006; Siikavuopio et al, 2007 Eddy et al, 2012). Many of these problems have been overcome, but to date there remains a lack of commercially available and economical formulated urchin diets (Lawrence and Lawrence, 2004; Lawrence et al, 2011; Suckling et al, 2011). Ensuring that depleted green urchins have a constant supply of macro algae (such as kelp, *Laminaria sp.*) is probably the most straightforward and cost-effective approach available to the industry in Maine. Vadas *et al* (2000) saw a significant improvement in gonad color and yield when green urchins were fed ad libitum with a mixed algal diet in the field through the summer. This relatively simple approach could be used to meet August market demand.

Environmental and husbandry factors should also be considered. Temperature and photoperiod can be manipulated to promote or delay gonad development (Walker and Lesser, 1998; Spirlet, 2000; Pearce et al 2002). Böttger et al (2006) showed that an invariant summer photoperiod yields gonads that do not initiate gametogenesis but do attain a large size as the NPs increase substantially in size. Smaller urchins in the size range of 40-50 mm test diameter respond most favorably to gonad enhancement and may be the most cost effective (Olave et al, 2001; Pearce et al., 2004; Woods et al, 2008). A starvation regime of two months can be used to reset the reproductive cycle and allow for gonad rebuilding (Spirlet et al, 2000). Urchins that are at gametogenesis can be induced to mass synchronized spawning by the release of sperm (Himmleman 1978; Gaudette et al 2006; Reuter and Levitan, 2010). After spawning, sea urchins can rebuild their gonads in 45 days or less (Spirlet et al, 2000; James et al, 2004). Urchins with good quality gonads but low yields can have improved yields after just 3-6 weeks of feeding (Cuthbert, 1995). Optimum stocking densities in raceway culture for on-growing are in the range of 7-8 kg per m^2 (Christiansen and Siikavuopio, 2007), but to maximize the economic efficiency of bulking much higher densities are required. The UrchinPlatter System™ proposed for use in this project enables stocking densities of up to 90 kg per m^2 (McCarron, 2007).

In Canada, bulking of *S. droebachiensis* began in 1993 when fisherman observed that gonad yields of harvested urchins ranged between 10 and 15%, but urchins harvested from certain areas had yields as high as 30% (Pearce and Robinson, 2010). Initial efforts used seaweeds, and the kelps *L. digitata* or *L. longicruris* produced the best gonad yield and quality (Cuthbert et al, 1995). User conflicts regarding harvesting kelp beds led Canadian researchers to shift their focus to formulated feeds. Initial formulations resulted in poor gonad quality (Pearce and Robinson, 2010; Robinson and Colborne, 1997), but later formulations gave more promising results (Robinson et al, 2002). Commercial scale bulking was initiated in Canada on a pilot scale in 1997, using green urchins held in an ocean corral system and fed *Laminaria*. Important lessons were learned from this effort, including the necessity of culling small urchins and limiting the extent of costly diving operations. It was concluded that this type of effort could be economically viable under certain conditions (Bridger et al, 1998). However, Canadian bulking efforts were halted in 2003 when Ross Island Salmon Ltd. suspended their program due to high mortality attributed to water quality issues (Pearce, 2010).

Sea urchin bulking is similar to lobster pounding, which is widely practiced in Maine to take advantage of winter price doubling. It lets harvesters and processors sell a value added product on a demand rather than supply basis. Chilled seawater and seaweed are the only inputs, but sufficient numbers of urchins need to be held with an efficient use of space and resources. It is straightforward in concept and practice: market size urchins are held and kept fed with any of several species of seaweed for about 12 weeks. The potential is to increase gonad yield from the 10% average seen with captured urchins up to 20-25%, while improving color and flavor. It creates opportunities for live sale and fresher product, which can double urchin value and encourage more sustainable capture methods.

The UrchinPlatter System™ for gonad enhancement

Although sea urchin bulking is considered an established procedure it has not yet been applied commercially on a widespread basis because of: 1) the previous lack of a commercially-viable culture system, and 2) the apparent need for artificial/composite feeds. In the proposed project these problems are addressed 1) by using a commercial sea urchin culture system developed in Ireland called the UrchinPlatter™ System, and 2) avoiding the need for artificial feeds by using freshly harvested seaweeds as the bulking feed.

The UrchinPlatter™ System is a high-density, land-based culture system for sea urchins developed by Gourmet Marine Ltd., Ireland. This system uses a proprietary feeding system that has been patented in the USA (USPTO number 7,798,102) and in 18 other countries. The basic unit of the UrchinPlatter™ System is the feeding system, called the Platter. The Platter is composed of two perforated plastic plates. The feed (seaweed or artificial) is sandwiched between these two plates, forming a rigid, planar surface onto which sea urchins can both attach to and feed from. Commercially, the Platter feeding units are combined with a cage structure, forming the UrchinPlatter™ cages, called Stacks. Sea urchins are put into the cage structure and consume feed from the two Platter units per cage. Sea urchin culture is performed by putting cages filled with animals and seaweed into a raceway-type (rectangular) tank. The cages are stacked vertically, horizontally and along the length of the raceway, resulting in a very high density of animals. Typically, the working stocking density in the UrchinPlatter™ system tanks is 50 to 90 kg per m^2 (or 10 to 18 lb per ft^2). These high stocking densities are only possible due to the Platter feeding system, which provides an attachment and feeding surface for the sea urchins, while ensuring that the central part of each Stack (cage) is relatively free of animals and feed to facilitate water movement in the tank.

The UrchinPlatter™ system was originally developed and assessed under laboratory conditions at University College Cork (UCC), Ireland (McCarron, 2007). A major part of this work involved bulking of the European sea urchin *Paracentrotus lividus*, which is of a similar size as the green sea urchin. In a typical bulking experiment from UCC, market size sea urchins were harvested from specific areas in Ireland during the sea urchin season. A percentage of the animals were sampled biometrically. The remaining animals were cultured for 12 weeks in the UrchinPlatter™ System using only freshly harvested seaweed (*Laminaria digitata*, at a feed rate of 10% total animal body weight per week). At the end of week 12, the cultured animals were sampled biometrically to determine the extent of bulking. As a control, sea urchins from the same bay were harvested and sampled. Mean gonad index increased from 27% to 54% in the experimental group, and there was an overall improvement in coloration (McCarron et al, 2010). Following the success of this work from 2001 to 2005, the UCC in conjunction with the Irish development body Enterprise Ireland submitted patent applications for the UrchinPlatter™ System. The UrchinPlatter™ System has since been independently validated by Dunmanus Seafoods Ltd, a sea urchin nursery and exporter based in Ireland, and in Chile under conditions equivalent to those in the proposed project: bulking of wild-harvested local/native sea urchins by feeding locally-supplied seaweeds. In all of these trials, there was a 2 to 2.5 fold increase in gonad index relative to the starting point.

Seaweed and sea urchin aquaculture

Seaweeds are the natural primary food source for the green sea urchin (Scheibling and Hatcher, 2001) and there are a number of highly nutritious and readily available species in the Gulf of Maine (e.g. *Porphyra, Palmaria, Saccharina, Alaria, Laminaria, Ulva).* Because of the lack of commercially available high-quality diets formulated to improve urchin gonad quality and the prohibitive price of the available feeds, the proposed project will use native seaweeds. This project will initially depend on local sustainably harvested *Saccharina latissima*, a species readily consumed by green urchins and one that has been shown to improve gonad yield and quality (Meidel and Scheibling, 1999; Vadas et al, 2000). *Saccharina latissima*, or sugar kelp, is a large, prostrate, sublittorial, highly productive kelp species distributed throughout the Gulf of Maine (Vadas et al, 2004). Each of the three proposed 12 week trials will require approximately 600 kg (1,300 lbs) of fresh kelp to feed 500 kg of urchins. At such a relatively small demonstration scale, wild harvested kelp will meet the needs of the project with minimal environmental impact (a partial sustainable harvest will be utilized, where the blade ends will be removed, leaving the actively growing stipe and base) and will not cause any user conflicts. At greater commercial scales significantly more kelp would be required.

There are obvious synergies between existing and developing seaweed industries in Maine and echiniculture. Maine has several established seaweed companies that sell wild-harvested, dried sea vegetables (Maine Coast Sea Vegetables, Maine Seaweed, Ironbound Island), and a new seaweed aquaculture-based company (Ocean Approved of Portland, ME) offering a frozen kelp sea vegetable. When wild kelp is harvested for the dried sea vegetable market, harvesters usually trim and dry it prior to selling to processors. During the trimming process, 10 to 20% of the biomass may be removed as waste. The central stipes and any blades covered with epiphytes are not suitable for human consumption, but are actually quite ideal for urchins, due to the extra protein found in the stipes and the epiphytes. A similar situation is found for companies such as Ocean Approved, who grow their own kelp and process it fresh for food products. Commercial scale urchin bulking facilities could be a ready buyer for the trimmings and waste kelp, which is now typically composted. The proposed project will utilize trimmings and waste kelp from local harvesters and processors, including Ocean Approved and Maine Sea Coast Vegetables.

Seaweed aquaculture is a small but growing new industry that is being developed in New England (Richardson, 2010; Benson, 2012). While seaweed is mainly cultivated for the sea vegetable market, there are numerous alternative markets that can be explored with the establishment of cultured crops. One of these potential markets will be the aquaculture feed market, especially for high-value herbivores (abalone, sea urchins). The technology for growing kelp is relatively straightforward (Edwards & Watson, 2011) and presents a low cost barrier to entry. This may provide an opportunity for traditional fishermen to diversify their operations to include a seasonal crop of seaweeds (the kelp culture season takes place from fall to spring, the off-season for most inshore lobstermen) for the sea vegetable market as well as for urchin feed. Maine Sea Grant has recently hired Sarah Redmond as a seaweed extension specialist based at the CCAR. In addition to providing outreach expertise for the proposed project, she will facilitate the use of kelp and potentially other seaweeds for the project. Currently, Redmond is involved in two projects that are developing seaweed hatchery culture technologies at CCAR for seeding of lines and nets for culture (with plans for *Saccharina, Porphyra*, and *Palmaria* culture), and also exploring the potential for kelp culture on existing shellfish lease sites in Maine and making connections between new growers and markets. The co-development of sea urchin enhancement technologies with a seaweed aquaculture industry will be to the benefit of both endeavors.

2) Research Work Plan

Sea Grant Strategic Plan and National Performance Measures

The proposed project furthers the goals of the National Sea Grant Strategic Plan. The project demonstrates methods to improve quality and profitability of sea urchins, whether captured or cultured, and creates new market opportunities for seaweed harvesters and growers. We will work with regulators to see if regulations and a proposed Fisheries Management Plan (FMP) can incorporate aquaculture, and we will work with harvesters to use more sustainable capture methods. These activities address Sea Grant Objective SSS2, Safe and Sustainable Seafood Supply. The project can indirectly further the goal of Sea Grant Objective SCD-1 to preserve Maine's working waterfronts and access for water dependant industries. Urchin grow-out and bulking may be economically viable for dockside facilities with seawater access.

The proposed project will have direct and measureable economic and societal benefits. This demonstration project transfers intensive aquaculture technology designed for value added enhancement of sea urchins to the fishing sector. It can be used with either aquacultured or captured urchins to potentially increase value by as much as two fold. It allows for additional income to be obtained from seafood products without increasing harvest levels. The proposed methods described below can increase employment, income and stability in the sea urchin harvesting and seaweed sectors on both the East and West coasts of the US. An economic analysis and market study are incorporated into the project to validate these hypotheses.

Demonstration of gonad enhancement under various conditions

Urchin bulking demonstration trials using the Gourmet Marine UrchinPlatter™ will be the platform upon which all other proposal components will be based, including the market study, seaweed culture, and collaborative efforts with the Maine DMR and the SUZC. If the project receives funding we will purchase a commercial sized UrchinPlatter™ System in Sept. 2012 for delivery to the Center for Cooperative Aquaculture Research (CCAR) in Franklin, ME. The system components includes the tank (1.2 m x 6.7 m) and 140 urchin holding/feeding cages, and it is capable of holding and bulking 500 kg of urchins. Dr. Gerry Mouzakitis of Gourmet Marine will provide practical and technical advice during all phases of the two year project.

The enhancement system will be integrated into an existing sea urchin aquaculture system held within a greenhouse at the CCAR facility. This is a recirculating seawater system equipped with a parabolic filter for solids removal, moving bed biofilter, foam fractionator, UV sterilizer, aeration and oxygen, and temperature control via a 5HP chilling unit. Ten thousand hatchery urchins are currently being grown to market size here, and will be available for the project. Delivery and installation of the UrchinPlatter™ should be completed by Dec. 2012, in time for the first demonstration trial to start in early 2013.

Gonad analysis

There will be three urchin enhancement trials occurring over the course of two years, and standardized analyses of gonad quality will be used for evaluation purposes. The trials will occur at the CCAR, and Steve Eddy and Nick Brown will directly oversee these efforts. In all trials, urchins harvested from the fishery from the same location as urchins harvested for the trials will be used as the control group. Gonad analyses will be done in all trials at the start, end, and throughout each trial at specific intervals, using 60+ randomly selected animals from each experimental group at each interval. Analysis will be performed by a graduate student supervised by Dr. Denise Skonberg of the Department of Food Science and Human Nutrition at the University of Maine. Quality parameters will include the gonad index (GI), color, texture, and moisture content. The gonad index is determined as (gonad wt. ÷ total wt.) × 100. Gonad color analyses will be conducted using a Hunter LabScan XE Colorimeter (Hunter Associates Laboratory, Reston, VA) standardized against white and black tiles (McBride et al. 2004, Phillips et al. 2009). CIE *L* (lightness), a* (redness),* and *b** (yellowness) values will be measured in triplicate for all samples, and the data will be used to calculate hue angle ($\tan^{-1}$ b/a) to further assess variations in color resulting from treatment. Gonad hardness and resilience will be evaluated by texture profile analysis as described by McBride et al. (2004) for urchin gonads. First, gonad height will be measured with a digital caliper. The gonads will then be compressed by a cylindrical plunger (diameter 50 mm) to 50% of the original gonad height at a speed of 50 mm/min^{-} using a 25 N load cell connected to a TA-XT2i texture analyzer (Texture Technologies) and hardness recorded as peak force in Newtons (Bourne 1968). Resilience is defined as how well the sample regains its original height after withdrawal of the plunger. Moisture content will be determined in 5g subsamples by overnight drying in a 100°C oven using AOAC draft drying method #950.46 (AOAC 2005) until a constant weight is achieved.

Other parameters common to urchin studies will also be measured. These include sex, test diameter (TD) measured with electronic calipers, and blotted wet weight, which will be measured to 0.1g accuracy on every urchin (or a sub-sample) used in each trial. In addition, we will measure test volume of a sub-sample of urchins sacrificed for gonad measurements, using seawater displacement at 10°C in a graduated cylinder. This will allow us to delineate the relationship between test volume, whole weight, and gonad index. A strong relationship between these three parameters could provide a non-lethal means of determining gonad index.

Trial #, Spring enhancement of captured and cultured urchins

Null Hypothesis #1: The gonad quality of captured urchins subjected to the enhancement protocols in the spring will not differ from the gonad quality of captured urchins that were not subjected to the enhancement protocols (wild urchins).

Null Hypothesis #2: The gonad quality of cultured urchins subjected to the enhancement protocols through the spring will be inferior to the gonad quality of captured urchins that were concurrently enhanced with the same protocols.

Null Hypothesis #3: The gonad quality of cultured urchins subjected to the enhancement protocols through the spring will not differ from the gonad quality of cultured urchins concurrently reared on a formulated diet under a standard culture regime.

The practical objectives of this trial are to: 1) demonstrate to aquaculturists and harvesters that it is possible to deliver high quality urchins to the market in late March/early April. At this time the regular fishing season has ended and wild urchins are normally approaching spawning, and therefore of low market quality; 2) demonstrate that the methods used here can improve gonad yields above the initial yields measured at the start of the trial, and; 3) demonstrate that the methods used here can improve the gonad quality of cultured urchins reared on formulated feed.

This trial will run from Jan., 2013 through Mar., 2013. Jim Wadsworth of Friendship International will purchase 250 kg of harvested urchins from selected divers, using project funds. The divers will be coached as to sustainable harvesting and handling methods that minimize damage and transportation mortality (hand harvesting, on-bottom culling, packing totes at lower levels, minimal air exposure, etc). These methods are already well understood but seldom practiced by harvesters, as they currently have little to gain from them. The divers will be instructed to bring in urchins that they suspect have low gonad yields, and an initial dockside appraisal will be done to evaluate gonad quality, using methods commonly employed by the industry. Only urchins averaging <12% yield will be used for this trial.

The urchins will be transported the same day they are harvested to the CCAR facility, placed in a flat-bottom raceway system, and held for two weeks without feed to monitor post-capture mortality. If mortality is below 5% after two weeks than the trial can commence; if not than additional urchins will need to be brought in. Healthy urchins will then be evenly but randomly stocked into 70 enhancement system cages at up to eight animals per compartment (32 animals per cage, 2,240 captured urchins in tank, biomass≈200 kg) (assumptions are that the avg. TD is 60 mm; avg. wt is 90 g). The other 70 cages will be stocked with the same number (up to 2,240) of aquacultured urchins of a similar size range as the captured urchins. These urchins have been reared since 2009 at the CCAR in V-shaped raceways at 6-8 kg/m^2, and fed a Norwegian formulated sea urchin diet (Nofima) (standard culture regime). In land based culture systems the reproductive cycle in urchins can become desynchronized. A starvation regime of two months can reset the reproductive cycle to allow for gonad rebuilding (Spirlet et al, 2000). Starvation or mass synchronized spawning both achieve the same aim of "purging" the gonads prior to market enhancement, and are methods that can be used by aquaculturists to produce a consistent product. Therefore, in this trial the cultured urchins selected for the trial will be starved for two months prior to enhancement. Initial biometric measurements of urchin size, gonad quality etc. will be conducted as previously described on 60 randomly selected urchins from each group prior to the start of the trial. Control groups will consist of wild urchins harvested at the end of the trial, and cultured urchins reared under the standard culture regime. Enhancement feeding will then commence, according to protocols previously validated with the European sea urchin. This consists of placing fresh seaweed between the feeding platters of each cage at ≈10% biomass once per week for the duration, until the trial end point of March 31, 2013. The urchins will be maintained at a constant 10°C with the recirculation system chiller, and held at a constant photoperiod of 8L:16D, by placing a black tarp over the tank. These simple methods may be adequate to prevent the urchins from completing gametogenesis, which they otherwise would ordinarily be prone to do (Walker and Lesser, 1998; Spirlet, 2000; Pearce et al 2002; Böttger et al, 2006). All of the urchins (60+) from two randomly chosen cages for each group (captured or cultured) will be sampled every 3 weeks as the trial progresses, and again at the end of the trial on March 31 (maximum 12 weeks). At this time, sixty urchins will be randomly harvested from the same geographic area where the urchins used in the trial were harvested, along with sixty urchins reared under the standard culture regime, and sacrificed for gonad analysis.

Trial #2, Summer gonad enhancement of captured urchins

Null Hypothesis #4: The gonad quality of captured urchins harvested at the end of the season in March and subjected to the enhancement protocols through the summer will be inferior at the end of the trial in August to the gonad quality of wild urchins at that time.
The practical objectives of this trial are to: 1) Demonstrate that the urchin fishery in Maine could use these methods to supply urchins for the Japanese Obon Holiday in mid-August, when demand and prices are high, but the GOM fishery is closed, and; 2) demonstrate that long term holding and enhancement of urchins can allow for targeted marketing.

This trial will run from Apr. 15, 2013 through Aug.10, 2013, and will be conducted on ≈450 kg of captured urchins purchased from divers at the end of the regular fishing season in March. Urchins harvested at this time are approaching spawning and have variable gonad quality, so mass induced spawning will be used to help purge the gonads and standardize the population. This will be accomplished by injecting 10-15 individuals with 0.5mls of a KCl solution, until several males have been induced to release milt, which should then trigger the entire population of ripe urchins to spawn (this occurred on a spontaneous basis at the CCAR in a population of 10,000 urchins following a temperature shock). The same stocking, feeding and sampling protocols used in Trial 1 will be followed, but the urchins will be reared at 12-14°C and under the ambient light regime for the GOM. At the end of the trial on Aug. 1, 120 urchins will be collected from the wild by an urchin diver and analyzed along with the enhanced urchins.

Trial 3, Winter enhancement and consumer acceptance of cultured and captured urchins

Null Hypothesis #5: Consumer acceptance of captured and aquacultured urchins subjected to the enhancement protocols will be lower than acceptance of wild urchins.

Null Hypothesis #6: Consumer acceptance of aquacultured urchins subjected to the enhancement protocols will be lower than acceptance of captured urchins subjected to the enhancement protocols

The practical objectives of this trial are to: 1) Demonstrate to harvesters and aquaculturists that enhanced urchins will be rated by consumers as similar to or even better than wild urchins, and; 2) demonstrate that consumer acceptance of enhanced cultured urchins will not be lower than acceptance of enhanced captured urchins.

This trial will run from Oct., 2013 through Dec., 2013, and will basically follow the same methods and numbers of animals used in Trial #1: urchins harvested from the fishery will be enhanced at the same time as urchins that have been reared in captivity, with gonad analysis being performed at the same intervals. However, at the end of this trial in late December there will be a validation of the enhancement methods with a Sensory Taste Panel conducted by Dr. Mary Camire of the Department of Food Science and Human Nutrition, University of Maine.

Sensory Taste Panel

Adults over the age of 18 years will be recruited from the greater Bangor, ME region, which has a population close to 150,00 persons, and from the University of Maine campus, whose international student population is largely from the People's Republic of China and Japan. Recruitment will be done via flyers, electronic notices on the University email system and local social networks. Individuals that are interested and consume uni at least twice per year will be specifically recruited. Several restaurants in Bangor serve sushi, and sushi is also available at all major grocery stores, so local residents are familiar with uni. Permission to conduct research subjects will be obtained from the University of Maine Institutional Review Board for the Protection of Human Subjects (IRB) if the project is funded. Persons who have an allergy to sea urchins or other seafood products or who do eat uni at least twice per year will not be allowed to participate in the study. The University's Consumer Testing Center has 12 individual assessment booths for privacy. Each booth has a computer connected to a sensory information management system (SIMS 2000, Sensory Computer System, Morristown, NJ, U.S.A.). The two evaluation rooms in the Center are climate-controlled with positive-pressure air flow to prevent odors from the food preparation area that could bias opinions. A combination of fluorescent and incandescent lighting will used. Each sample will be assigned a randomly-generated three digit code by SIMS and a 9-point hedonic scale (1 = dislike extremely; 5 = neither like nor dislike; 9 = like extremely) for samples' color, appearance, aroma, firmness, flavor and overall acceptability (Peryam and Pilgrim, 1957) will be used to assess liking. Food scientists have agreed over the years to treat such data as interval data. General demographic data (age, gender, uni consumption habits) will also be collected. In the first test, SIMS will randomly assign either the hatchery-raised or the wild-caught urchins fed seaweed to be served first to half of the subjects to prevent any serving order bias. In the second test, uni from urchins fed the best formulated feed and those fed the least expensive feed will be compared to uni from seaweed-fed urchins grown under similar conditions. Hedonic data will be analyzed with SAS through SIMS by analysis of variance. Means will be compared with Tukey's test. Demographic data will be analyzed by chi^2.

Macro-algae enhancement diets

In all of the above trials, a blend of wild harvested and cultured macro-algae will be used as the enhancement diet, consisting primarily of the sugar kelp *Saccharina latissima* and possibly other species depending upon availability. Since this is a "real time" demonstration project and the nutritional profile of macro-algae varies seasonally, it would be counter-productive to use a standardized diet. However, we will include analyses of the nutritional profile (protein, carbohydrate, total fat, ash, and moisture only) of the macro-algae to detect seasonal variation throughout the project, to be performed by an independent lab (New Jersey Feed Labs).

Two project objectives are to: 1) Develop markets for harvested and cultured seaweed as an aquaculture feed, and; 2) encourage shellfish growers and fishermen to engage in seaweed aquaculture to provide feed for urchins. Sarah Redmond of Maine Sea Grant will be responsible for these efforts, which are primarily of an outreach nature. She will purchase seaweed with project funds from existing seaweed companies and harvesters, focusing primarily upon procuring trimmings and low quality blades considered as waste. She will also work to recruit an existing or new grower to establish a kelp line to provide kelp for the third enhancement trial. Currently, Sara and Dr. Susan Brawley of the University of Maine have been developing tank culture techniques at the CCAR for *Porphyra*, and plan on doing the same with other valuable seaweed species. The possibilities are many, but include using macro-algae produced for bioremediation of aquaculture wastes as an urchin feed. This would only be feasible if there were a demonstrated utility, such as commercial scale urchin enhancement.

Marketing Strategy and Cost/Benefit Analysis

A key component of the proposed project is to determine the potential value of the demonstrated enhancement methods to the industry. This will be performed by two resource economists; Dr. Jenny Sun of the Gulf of Maine Research Institute, and Dr. Fu-Sung “Frank” Chiang, Visiting Scholar, School of Economics, University of Maine.

In order to increase landings value to the sea urchin fishery, a cost/benefit analysis will be performed to determine the profits/losses as well as Net Present Value (NPV) of the results for different time periods of conditioning. In addition, the domestic and international market information of Maine's sea urchins will be collect to analyze the current marketing channels of Maine's sea urchins and the market potentials in the emerging Asian countries to form the marketing strategies for the domestic and international markets.

At the end of each enhancement trial, with about 500 kg urchins per trial, Jim Wadsworth will explore marketing options that result in the best possible price for enhanced urchins. The dynamics of the value chain will be determined as follows: a) flows of physical quantities of outputs, inputs and investment items; b) flows of current, discounted and cumulative costs, benefits, and net benefits; c) flows of incremental (with-without project) current, discounted and cumulative net benefits; and d) indicators of financial and economic viability such as the Net Present Value (NPV), the Internal Rate of Return (IRR), the Benefit/Cost Ratio (BCR), the Switching Values (SVs) and Sensitivity tests.

The analysis will also take into account the economics of the fishers, including the revenues from harvests (volume multiplied by price) and their costs. Where useful, we will incorporate pricing dynamics for urchins delivered during different culturing seasons, for example for harvests from the cultured urchins delivered in late March/early April (trial #1) versus in August (trial #2) and in December (trail #3), and for price variations at domestic and international markets. In each of the case studies we will outline the results in terms of weeks. For the NPV calculations we will use a discount rate ranging from 6-10% per annum, which represents the estimated cost of capital. The short-term annual profits/losses, and to some extent the 5-year NPVs are most relevant for those players who, due to uncertainty of future cash flows, may only look at the economic situation for the next few years to guide their behavior.

Management issues and sustainability

If it is economically viable, urchin bulking may allow for a new approach towards management of the urchin fishery that promotes more sustainable capture methods, and adds value to the fishery without adding to harvest levels. The use of other aquaculture tools to benefit the fishery, such as hatchery production for reseeding, also merit further discussion. To examine and facilitate these possibilities within the context of regulatory management, the project includes Margaret Hunter and Trisha De Graff of the Maine DMR, Dr. Larry Harris of the University of New Hampshire, and Mick Devin of the University of Maine as unfunded Investigators. Margaret Hunter is the DMR urchin biologist, and has worked on urchin fishery management issues for many years. Trisha De Graff has been charged with coordinating development of the FMP. Larry Harris is on the SUZC Scientific Advisory committee as the marine scientist, and has extensive knowledge of urchin biology and ecology. Mick Devin is on the SUZC as the aquaculture representative and was a pioneer in sea urchin aquaculture efforts in Maine starting in the 1990's. Their roles in the project are to provide expertise and advice, and to facilitate discussion of areas of common ground between sea urchin aquaculture and fisheries management. The work plan for this project aspect includes the following components:

1) Regular attendance at SUZC meetings by Steve Eddy, Nick Brown, Jim Wadsworth, and Sarah Redmond to explain project methods and outcomes, and provide input regarding regulatory issues, urchin bulking, and other aquaculture methods.
2) Hold discussions on ways in which urchin bulking and other aquaculture methods can be used to promote sustainability of the resource.
3) Work with the SUZC and DMR to determine if urchin aquaculture can or even should be included as part of the Fisheries Management Plan.

Milestone Chart		
Year	**mo/yr**	**Milestone**
1	9/12-12/12	Establish commercial scale sea urchin enhancement system at the CCAR.
1	1/13-4/13	Demonstrate spring sea urchin enhancement with captured and cultured urchins. Determine market value for enhanced urchins in March/April.
1	1/13-8/13	Procure seaweed from harvesters and processors for use as urchin feed.
1	1/13-4/13	Recruit seaweed grower to supply seaweed for urchin feed.
1	4/13-8/13	Demonstrate summer sea urchin enhancement with captured urchins. Determine market value for sale during high demand Japanese Obon Holiday season.
2	9/13-12/13	Demonstrate winter sea urchin enhancement with captured and cultured urchins. Determine market value for sale in December
2	12/13	Conduct sensory taste panel to evaluate consumer acceptance.
2	1/14-4/14	Economic analysis and completion of market study
2	1/14-4/14	Produce and disseminate a 4-6 page brochure describing bulking methods, economic value, and sustainable harvesting methods
2	4/14-9/14	Complete analysis of results, write final project report. Graduate student finishes thesis.
1,2	9/12-9/14	Work with Maine DMR and SUZC on fishermen outreach, management considerations, and Fisheries Management Plan.

3) Outcomes
We anticipate that the proposed project will result in the following outcomes:

1) **Lead to the establishment of one or more commercial sea urchin bulking facilities in Maine and adoption of this technology in other regions, such as California.** If the project demonstrates that sea urchin bulking is sufficiently profitable, than investors and processors will be motivated to undertake it. This will create jobs and add value to the resource without requiring higher harvest levels.
2) **Lead to further development of sea urchin aquaculture in Maine and other regions.** Sea urchins have been identified as a potential new aquaculture species for North America, but to date no evidence as to technical and economic viability has been provided based on a full grow-out cycle from hatchery to market. The CCAR has the first crop of tank reared market sized urchins ever produced in the US and is very close to completing this cycle. The proposed project provides the resources to bring these efforts to completion using the best available technology. The market study included within the project will be used to provide evidence of economic viability and/or identify areas where further progress is required. This market study will be published on-line and available at large. In addition, the results from this project will be included in a forthcoming text on echinoderm aquaculture edited by Brown and Eddy (to be published by Wiley).
3) **Result in more sustainable sea urchin harvest methods.** Sea urchin bulking requires that harvesters adopt time intensive but more sustainable harvesting methods that result in less bycatch of undersized or oversized urchins, less culling mortality, and gentler handling. They will be motivated to do this if it allows them to make more money with better quality urchins.
4) **Result in greater acceptance and adoption of aquaculture by fishermen.** The project outreach objectives include demonstrating to fishermen how the proposed methods can be used by them to add income without impeding their fishing activities. A measureable outcome will be in terms of the number of fishermen involved in aquaculture activities as a result of this project, such as growing seaweed, participating in urchin bulking co-ops, or out-planting hatchery seed on bottom.
5) **Lead to the use of cultured seaweed as an aquaculture feed for urchins.** Urchin bulking requires seaweed and can provide seaweed growers with a market for products now considered as low value waste or unsuitable for human consumption, such as seaweed grown for bioremediation. Immediate measurable outcomes are demonstration of such use and pricing data that can be used to inform seaweed and urchin growers.
6) **Inclusion of sea urchin aquaculture in Fishery Management Plans.** We believe sea urchin aquaculture can help make the capture fishery more sustainable without directly competing with fishermen. A measurable project outcome will be language in the FMP for Maine that describes how this can be done. The State of California has identified the development of an FMP for the red sea urchin fishery as a management priority, and the Maine FMP could serve as a model. Sea urchin and seaweed aquaculture could be viable in California, which has existing commercial sectors for both crops.

The proposed research will inform specific regulatory decisions. Aquaculture development occurs in the context of capture fisheries and their regulations. Rules on legal market size, season length, limited entry and other fisheries regulations must be taken into account by aquaculturists when they grow and market their product. Evidence provided by this demonstration project can be used by the Maine DMR and the SUZC to inform the regulatory process. If capture regulations can be modified to account for aquaculture practices and promote sustainability, then the resource benefits and fishermen gain more flexibility and control. Though focused on the green sea urchin, the project is a collaborative effort requiring partnerships with the fishing community, regulators and aquaculturists that gives it greater scope. **The project addresses socio-economic issues limiting participation of fishermen in aquaculture.** It has long been proposed that fishermen participate in and benefit from aquaculture. However, the fishing community as a whole has an ambivalent view of aquaculture, often seeing it as a threat. This proposal seeks to integrate urchin and seaweed aquaculture with traditional fishing practices in a way that will be acceptable, intuitive, and adaptable to the fishing community. It will demonstrate culture technology to fishermen in a way that will have measurable outcomes within two years. Resource economists will conduct market and cost/benefit analysis to provide evidence for potential economic impact. If fishermen can gain financially from aquaculture while continuing to fish, then this may help increase acceptance. If fishermen are more accepting and knowledgeable of aquaculture, then they will have more options in the event of fisheries decline.

4) Outreach Plan

The proposed demonstration project essentially is an outreach project, as it requires the collaboration and participation of urchin harvesters, buyers, the Sea Urchin Zone Council, and the Maine DMR. Many aspects of the project will be discussed at open forums, such as SUZC meetings, which are attended by a large segment of the urchin industry. Attendance and discussion at SUZC meetings by project participants is required as part of the work plan to investigate inclusion of sea urchin aquaculture into the FMP and to address concerns and questions harvesters may have regarding aquaculture and sea urchin bulking. Jim Wadsworth will work with harvesters to ensure that urchins procured for the project are captured using sustainable methods. The divers who supply urchins for the project will be invited to the CCAR to see how "their" urchins are doing. Jim has extensive contacts in the urchin and lobster industries and is well positioned to attract investment funds to carry the demonstration project, should it prove viable, to full commercialization. Sarah Redmond will be engaged with seaweed producers to procure the seaweed required as feed, and will work to recruit one or more growers to supply kelp for the project. In the course of these activities she will interact with seaweed harvesters, growers, and processors, as well as shellfish growers, all of whom will be informed of the project goals. The project will produce a marketing study and economic analysis of the sea urchin fishery, to be posted online and available at large. We will also write and publish a 4-6 page brochure describing the methods, market potential, and the sustainable harvesting methods required to make urchin bulking successful. This will be disseminated via SUZC meetings and the Maine Fishermen's Forum. Finally, Nick Brown and Steve Eddy are in the process of editing a text on the aquaculture of echinoderms, to be published by John Wiley, Publishers. The text will consist of selected contributions and cover global production. The methods and results from this demonstration project will be included in this text.

5) Coordination with other efforts

As previously described, the CCAR is currently in the third year of an NRAC sponsored sea urchin aquaculture project. The project proposed here picks up where the NRAC project leaves off, and leverages the resources acquired during the NRAC project for the purposes of this proposal.