Nick Starešinić[*]
Erica A. G. Vidal[**]
Leigh S. Walsh[***]

ISSN 0469-6255
(24-36)

NEW SPECIES FOR MARICULTURE IN THE EASTERN ADRIATIC

Nove vrste - marikultura na istočnom Jadranu

UDK 639.2 (262.3)
Pregledni članak
Review

Abstract

As production of seabass and sea bream has expanded in the Mediterranean over the past decade, prices for each have fallen dramatically. The lower revenues that have resulted have forced some once-profitable producers out of business and made entry into the market by new producers much more difficult. This reality must be taken into account in formulating any successful national or enterprise-level development plan based on production of these "old" species.

Introduction of "new" commercial species is one possible response, and several fish and invertebrates have received attention in this regard. Of the invertebrates, one echinoderm, the sea urchin Paracentrotus lividus, and two molluscs, the cuttlefish Sepia officinalis and the common octopus Octopus vulgaris, appear to have sufficient potential for Croatian mariculture to warrant closer examination of their advantages and disadvantages, and to invest the capital and effort on applied research to overcome the latter.

In the case of the cephalopods, full commercialization of both cuttlefish and octopus is limited by availability of an economical crustacean feed for early stages. Further, although culture systems for cuttlefish are well established, a octopus grow-out system that satisfactorily reduces the animal's natural agonistic tendencies while permitting unencumbered routine feeding and maintenance has yet to be identified.

Commercial sea urchin cultivation is limited by several factors, including an efficient juvenile feed; but the quickest route to sea urchin commercialization is out-of-season gonad (roe) enhancement of natural stock, analogous to the way in which the successful Croatian tuna-ranching industry operates.

The success of this 'bulking' process depends upon availability of an effective diet and a containment system that addresses the peculiarities of sea urchin behavior in captivity.

Of the three species examined briefly here, cuttlefish can be commercialized the fastest. The next step in cuttlefish development is to operate pilot-scale production trials to evaluate its economic feasibility under Croatian conditions. 'Bulking' of sea urchin offers the next most promising new commercial opportunity and merits feed trials using at least one of several published feed formulations, perhaps followed by a diet of local macroalgae to 'polish' the product's taste to market standards. Octopus now appears to be the least ready of the three. A positive step in its development in Croatia is to transfer the latest techniques on paralarval rearing, the better to be prepared to take full commercial advantage of further advances in this area as they become available.

Sažetak

Radi povećane produkcije lubina i komarče na Mediteranu, u posljednjih deset godina njihova je cijena znatno pala. Smanjeni prihodi prisilili su mnoge proizvođače da napuste ovaj posao, a ulazak novih proizvođača na tržište postaje sve teži. Ova činjenica mora se uzeti u obzir pri izradi razvojnog plana koji se zasniva na produkciji starih vrsta u uzgoju, bilo to na nacionalnoj razini ili na razini poduzetništva.

[*]**dr. sc. Nick Starešinić,' EcoMar Mariculture, Galveston, TX 77550 USA, *aquacalc@yahoo.com***
[**]**dr. sc. Erica A.G. Vidal, Laboratório de Maricultura, Departamento de Oceanografia. Fundação Universidade do Rio Grande - FURG, Cx. P. 474. Rio Grande, R.S. CEP 96 201-900 BRASIL**
[***]**mr. sc. Leigh S. Walsh, National Resource Center for Cephalopods, The University of Texas Medical Branch, 301 University Blvd, Ewing Hall Galveston, TX 77555-1163 USA**

Mogući odgovor na ovu problematiku je unos novih vrsta u uzgoj. Neke ribe i beskralježnjaci već neko vrijeme privlače pozornost kao novi kandidati za akvakulturu. U skupini beskralježnjaka pojavljuju se tri potencijalne vrste za uzgoj: morski ježinac, Paracentrotus lividus iz razreda Echinoidea, i dva pripadnika reda mekušaca, sipa Sepia officinalis i hobotnica Octopus vulgaris. Ove tri vrste imaju dovoljan potencijal da bi se omogućio detaljniji pregled prednosti i nedostataka njihova uzgoja, te investirao novac u primijenjena istraživanja kako bi se svladali nedostaci.

Kod glavonožaca je limitirajući faktor komercijalne proizvodnje raspoloživost račića kojima se koristi kao hranom u ranim razvojnim fazama sipe i hobotnice. Iako je uzgojni sustav za sipu već poznat, za hobotnicu, onaj kojim bi se uspješno reducirale njezine antagonističke tendencije i ujedno osigurala nesmetana hranidba i održavanje, još uvijek nije poznat.

Pri komercijalnom uzgoju ježinaca prepoznato je nekoliko limitirajućih čimbenika, među kojima je nedovoljna količina hrane za mlađ. Najbrži put do komercijalizacije je izvansezonsko obogaćivanje gonada (ikre) prirodnih populacija, slično uspješnom načinu uzgoja tuna u Hrvatskoj. Uspjeh metode tovljenja ovisi o raspoloživosti hrane i adekvatnoga uzgojnog sustava kojima se uzimaju u obzir behavioristička karakteristike ježinca u zatočeništvu.

Od tri proučavane vrste, sipa ima najbržu mogućnost komercijalizacije. Da bi se procijenio potencijal njezina uzgoja, u Hrvatskoj je potrebno napraviti eksperimentalni dizajn proizvodnje. Sljedeća tehnologija obećavajuća za komercijalizaciju marikulture u Hrvatskoj jest kondicioniranje gonada ježinca, pri čemu valja ispitati uporabivost nekih od postojećih hranjiva, uz mogući dodatak lokalnih alga kako bi se usavršio okus proizvoda i zadovoljile tržišne potrebe. Od tri spomenute vrste, hobotnica je najmanje pogodna za komercijalizaciju. U Hrvatskoj se trenutno mogu primijeniti dosadašnja znanja i tehnologije na ličinačkom uzgoju ove vrste kako bi bila spremna za daljnju komercijalizaciju, ali tek uz nove znanstvene spoznaje.

New Species for Old

Vrste u uzgoju – Nove za Stare

One natural approach to mariculture development is to increase production of species already under successful cultivation. Advantages of this path are that the production technology—containment structures, feed, fingerlings, and disease-prevention measures—is mature and readily acquired; market channels are well established; and economic data that permit confident composition of *pro forma* financial statements are available.

At some point, however, further expansion of these "old" species confronts a serious challenge: After supply has attained some threshold, these species become commodities. That is, there is sufficient product in the market that most consumers differentiate their purchases mainly according to price. Competition among producers thus intensifies and unit prices decrease. Faced with smaller profit margins, the industry is forced to re-structure. Larger producers are better suited to survive by capturing the economies of scale [61]. Survival is much less certain for small producers, and new producers find it much more difficult to enter the market.

This has been the case with farmed salmon, penaeid shrimp, and, in the Mediterranean, seabass and sea bream. In the case of seabass and sea bream, production has grown over the past decade at an astounding average annual rate of nearly 30%. Thus, from 1990 to 2002, the wholesale per-kg price of sea bream has plummeted from € 7.63 to 3.46, and that of sea bass has fallen from € 8.22 to 3.90 [2]. The situation is such that even operationally efficient, long-time producers are losing money, forcing some out of the market. Spanish producers refer to this as el efecto griego, as Greece, which now annually produces more than 100,000 MT of both species combined, is far-and-away the most responsible.

Table 1. Average production Costs, 400 MT/yr Spanish lubin farm (after Cabello, 2001.)

Tablica 1. Prosječni troškovi proizvodnje, 400 MT/godišnje Uzgajalište lubina, Španjolska (Cabello, 2001.)

Item	€/kg
fingerlings	1,26
feed	1,65
insurance	0,19
packing	0,72
fixed costs	1,41
Total Cost of Production	**5,23**

This point is worth emphasizing at the enterprise level with a few rough—but accurate—figures from a well-run 400-MT-per-year Spanish farm [9]: The total cost of producing one kilogram of fish (Table I), € 5.23, is more than € 1.30 higher than the average market price given above. Such farms, condemned to lose money, either must adapt to the new business environment or face certain economic extinction.

Those that choose to fight usually attempt to implement strategies that lower fixed costs. As Cabello (2001) notes, these might include using larger nets (from the old 2.000-m^3 nets to those of over 12.000 m^3), increasing total farm production (some seek permitting for 1200 to 3000 MT/yr), and installing automated feeding systems (otherwise, using standard feeding methods, a 2000-MT farm at peak summer feeding rates requires a feeding team of 40 people and 10 feed-boats).

The practical result is that, at present, Spanish farms smaller than 600 MT/yr are unprofitable (R. Barrera, Valenciana de Acuicultura S.A., pers. comm.). The break-even farm size indeed may be smaller in other Mediterranean countries, such as Turkey (E.

Gozgozoglu, Ministry of Agriculture and Rural Affairs, Ankara, pers. comm.), where the cost structure is different; but no country that is serious about developing this sector of its economy can afford to isolate itself from international markets, and so eventually will be exposed to the same industry pressures as producers in Spain. Thus, they must reduce production costs and/or differentiate their product by adding value.

(Subsidies on which some Croatian white-fish producers now depend—Kn 5/kg for mainland- and Kn 7/kg for island-based producers—may not survive accession to the WTO and eventual integration into the EU.)

Bottom-line: Without some special regional advantage that dramatically alters the structure of the production budget or increases sales revenue, it will be increasingly difficult for new producers to enter the "old" species market and be profitable.

What makes a "new" species a good candidate for development?

Kako odrediti novu potencijalnu vrstu za akvakulturu?

Another approach is to introduce so-called "new" species. These are "new" in the commercial sense, and so are either not exploited at all or perhaps under-exploited; in either case, they are not market commodities and thus support attractive prices. Three high-level headings assist initial evaluation of the potential for developing a new species for commercialization. These are: its basic biology, available production technology, and its market acceptability.

Biology

Biologija

The basic biology question is this: *Does this species already occur in the region?* If it does NOT, then it is likely that even if the local climate does not limit its zoogeographic distribution, government regulations concerning introduction of exotic (non-endemic) species will. If that is the case—and barring some very special exceptions that justify confining production to expensive "bio-secure" facilities that completely isolate the species from the natural environment—it is not a candidate for commercial production.

If the species in question does occur naturally within the region, the next question is: *Does it require any special feed or environmental conditions to grow and reproduce in captivity?* If so, these must be reviewed carefully to determine if an applied research program of reasonable scope will resolve such key biological issues. *Bottom-line*: Except in very special cases dictated by market considerations, if the candidate's basic biology is not sufficiently known, the species is not attractive for quick commercialization.

Production Technology

Tehnologija proizvodnje

The basic question: *Is there a set of economical technology components available to effect production?*

Expanding this question to highlight several key components: *Are suitable containment structures—whether cages, ponds, or land-based closed systems—obtainable on the open market? Is there an affordable commercial feed? Can the young be acquired at a favorable price?*

The technologies required to carry out the complete production cycle—traditionally broken down as maturation, larval rearing, and grow-out—need not all be in place to begin commercial operations. In fact, the development process is never linear. In the case of penaeid shrimp, the early industry was based on pumping naturally occurring postlarval shrimp into ponds in which they fed on natural feed. Several modifications of formulated feeds later were introduced, and pond designs were perfected. Finally, maturation and production of hatchery-reared postlarvae was implemented in the mid 1980s, thereby 'closing' the production cycle and permitting rapid growth of the industry. Similarly, tuna production still is in its early stages of development, with fattening in sea-cages proving to be very profitable in Croatia and elsewhere. Recent Japanese advances in hatchery techniques [1], when elevated to a commercial level, promise to stimulate growth of the tuna industry in the same fashion.

Bottom-line: If an essential production component, such as feed or seed, is not available, the species still may be an attractive candidate for commercialization if techniques for enhancing wild-stock can be implemented economically.

The Market, The Market, The Market,

Tržište

Mariculture is first and foremost a business, and the survival of any business depends on the market for its product. The basic market question thus is very, very simple: *If you produce this species, will anyone buy it?* If not...*forget it*—regardless of how "attractive" it might be biologically, or how much you might like to eat it! If it is indeed marketable, the next question is: *Will customers buy your product at a price that provides a healthy profit?*

Bottom-line: If the candidate species is marketable, the next step is to prepare a detailed analysis that, at a minimum, considers three general market segments: Domestic, Tourist, and Export.

Researcher or Businessman—or both?

Istraživač ili poslovan čovijek – ili oba ?

The evaluation process outlined very briefly above is iterative: Each of the three topics—biology, technology, and market—must be examined several times before arriving at a rational decision regarding a new candidate for mariculture. Where one begins the analysis, however, and the relative emphasis that one places on each of the three headings, identifies clearly whether the analyst is a researcher or a businessman.

For example, a typical group with a biology background can be expected to focus on such topics as a species' natural population density, sex ratio, habitat structure, and features of reproduction and feeding ecology. This often leads to a line of research that elucidates interesting life-history features, but which is of little—if any—value to building a business. Commercial development thus may be slowed to a glacial pace if a research group controls a mariculture program. To exaggerate this point: Limited resources should not be dedicated to calculating the third decimal place of the population density of, say, sea urchins in a particular bay, as such information is altogether unimportant for advancing commercialization. (Ask a producer in Greece the natural population density of seabass and sea bream in their local waters—as the senior author has done—and very likely they will have no idea at all; yet that country earns over € 300 million annually culturing these species without such information.)

The businessman is at the other end of the spectrum. His decisions are market-driven. He typically first examines whether anyone actually will BUY the product under consideration and, if so, at what realistic price. But a pure businessman will encounter difficulties implementing a commercial project if he ignores the relevant biological realities—principle among these being growth rate, survivorship, and feeding rate—that most concern a dedicated applied mariculture research team.

How are these two extreme positions resolved? The answer lies in the fact that mariculture is first and foremost a business activity. Thus, the businessman's approach is the more rational: Begin the analysis by examining the market. This is absolutely the best, most efficient way to identify new species for commercialization. It is not, however, a substitute for assembling an interdisciplinary development team that includes applied biologists. Such a team best is headed by someone with experience in both business and biology, though perhaps a specialist in neither.

Some Regional Candidates

Lokalne potencijalne vrste

Of several candidates for mariculture development in the Eastern Adriatic [26, 58, 35], three invertebrates are considered here: one echinoderm, the sea urchin *Paracentrotus lividus*, and two molluscs, the cuttlefish *Sepia officinalis* and the common octopus *Octopus vulgaris*. Each appears to offer sufficient potential for Croatian mariculture to warrant closer examination of their advantages and disadvantages. This is done briefly below.

Sea Urchins

Morski Ježinac

General

There a over 700 species of sea urchins in the world, and the range of environments to which they have adapted is truly impressive: from the Poles to the Tropics; and from the intertidal zone to the deep sea. Several dozen urchin species of commercial importance are found in Japan, North America, and Chile. In the Mediterranean, one is of dominant economic value, *Paracentrotus lividus*.

The custom of eating urchin roe likely extends far back into the Mediterranean's unwritten prehistory. The Classical literature of the Greeks and Romans provides clear evidence of this tradition, with the earliest written reference to urchins as a food appearing in the 6th-Century BC comic play of Epixarmus, *The Marriage of Hebe*. Other well-known authors—Horace and Pliny, for example—make passing references; and about 2.400 years ago Aristotle provided the first detailed scientific description of basic urchin anatomy, reproduction, and habits—including a note on their use by the Greeks as food.

Hard evidence is preserved in Pompeii, the Roman city south of present-day Napoli that was destroyed in the famous 79 AD eruption of Mount Vesuvius. Lava-encrusted shells strewn amongst the ruins of some excavated kitchens attest to the fact that urchins were part of the diet of these unfortunate early Romans.

A few Classical authors even offer urchin recipes prepared in the Mediterranean nearly two thousand years ago. The 1st Century AD gourmet Apicius provides several recipes. His recipe for an ancient urchin omelet runs thusly: "Cook the urchins in boiling water. Remove the meat [sic]. Add to a sauce made of bay leaves, pepper, honey broth, and a little olive oil. Stir in eggs. Sprinkle with pepper and serve." Athenaeus, in his 3rd Century AD gastronomic work *Deipnosophistae* (*The Banquet of the Learned*), describes an urchin dish seasoned with "...honey, vinegar, parsley, and mint" and served as an appetizer.

Urchins still play a role in the cuisine of the modern Mediterranean, with today's Greeks continuing the tradition of their ancestors. Throughout the Hellenic mainland and especially on the islands urchins are eaten raw with a bit of lemon, or used as a principle ingredient of popular seafood dishes, such as with rice seasoned by typical Mediterranean herbs and spices.

Across the Adriatic, Italians highly prize the taste of sea urchins (*ricci di mare*), and fresh urchins can be found, in season, in markets of southern Italy, Sicily, and Sardegna. In the urchin's peak reproductive season—February and March—the picturesque Mediterranean town of Alghero on Sardegna's rugged west coast holds its annual *Sagra di Bogamarì—a sea urchin* festival. During this time sea urchin may be bought fresh from vendors that line via Lido in the morning. And just as fruit and vegetable sellers in on the open-air markets display samples of their products sliced cleanly in half to advertise their quality, Alghero's sea urchin sellers display some animals with their bottom neatly cut off to reveal the thick, reddish-orange, five-pointed stella of roe inside.

Fig 1. Street-side urchin vendor in Alghero, Sardegna

Slika 1. Prodaja ježinaca na ulici Alghera, Sardinija

Izvor: Nick Starešinić

During this time Sardinian restaurants feature the island's traditional pasta dishes based on urchin roe, a treat that attracts an increasing number of tourists from around Italy for sea urchin-sampling weekends during the low-tourism winter season. In Oristano, sea urchin often is accompanied by their particularly appropriate regional white wine, *Vernaccia*, somewhat reminiscent of Korčula's *Grk* when produced in the traditional way. Another clear sign of Italy's love affair with urchins: Persistent stories of large mounds of empty sea urchin shells that 'magically' appear along the shores of the Croatian mainland and islands during *feragosto*—the work of appreciative Italian tourists with hearty appetites for fresh urchin roe!

The French refer to the roe of *Paracentrotus lividus*, the edible urchin found throughout the Mediterranean and in Croatian waters, as *corail*, a reference to the similarity of its bright reddish-orange color to that of the valuable Mediterranean red coral used in jewelry. As in Sardegna, some parts of Southern France celebrate their love of urchin roe with an annual urchin festival—*l'oursinade*—that takes place in February and March, when the roe is at its natural peak. During these festivals urchins most often are consumed raw with lemon, a bit of bread, and—*bien sûr*!—the proper white wine.

The Japanese are especially knowledgeable consumers. They expect very high quality in all of their products and are willing to pay for it. Urchin roe (uni, as illustrated on the left in Hiragana) is no exception. *Uni* must meet high standards of freshness, color, taste, size, and texture to be acceptable in the Japanese market.

The best quality roe is reserved for the fresh product used in the sushi trade, and highest prices are paid for the roe of native Japanese species. Of the six major Japanese species, the White Urchin is especially prized. But imports such as Red Urchin (*Strongylocentrous franciscanus*) roe from California have passed the quality test and fetch attractive prices. In the first week of January—a time of the year characterized by high prices—fresh *uni* from the US wholesaled in the Tokyo Central Market (2001) at an average of over 40 €/kg. (The average price of all imported urchin roe, about 29 €/kg, was about the same as the average wholesale price of fresh Bluefin Tuna during the same period.)

That's the reality, as reported by official Japanese customs statistics. But *everybody* wants to hear the highest price, so here it is...but *don't* base a business plan on getting this price for sea urchin produced in Croatia: During the Christmas – New Year Holidays, a period during which it may be given as a special gift, sea urchin of the most superior quality can reach a wholesale price of over € 112 for a 300-g pack. The per-kg price thus is over € 370. (Anyone truly serious about producing sea urchin will *ignore* that number.)

The opportunity for culturing sea urchin arises from both the relatively high price of its roe and the general decrease in supply, owing to over-fishing of natural stocks in many areas [36].

Biology

Biologija

Urchins are, in fact, one of the most studied animals in the sea. Their reproductive biology first was studied in the mid-1800s (*sic*) and now is so well known that they are the model animal for embryology. Their genetic studies even have advanced to the point that there is a Sea Urchin Genome Project [10]! Thus, there is absolutely no need to spend years repeating work on basic biology that, for example, was completed in the 1930s. Details are found easily in the open literature, and differences that may characterize some small population along the coast may be biologically interesting, but unimportant in the march to commercialization.

Are there interesting questions within the domain of basic biological research? Of course. But if the objective is to build the foundation of a strong business that creates jobs and benefits the larger coastal economy, the limited research resources available must be focused tightly on questions of a strictly applied nature that further commercial development.

Technology

Tehnologija

Research groups around the world—notably in Japan, Canada, Scotland, Belgium, Chile, France, and the US—have been hard at work for more than 20 years developing techniques to grow urchins for their valuable roe. There thus is a large and growing literature on stock enhancement, stock translocation, sea ranching, and land-based systems [27, 13, 32, 71]. Notable advances have been made in the critical areas of hatchery development, grow-out containment systems, and feed formulation [11, 39, 37, 52]. A key to launching commercial production is an efficient feed. In fact, two feeds are required: one that produces rapid growth in body mass from juveniles to adults; and one that promotes large, high-quality roe [39, 63]. Owing to the relatively slower feeding rates of sea urchins, their feed must be more stable in water than that typical of cultured fish and shrimp; and special care must be taken to exclude ingredients that impart an unacceptably bitter taste to the urchin's roe [45], as this will significantly—or completely!—erode its market value.

Research also has been devoted to designing efficient containment systems. One branch of research has addressed the strong tendency of urchins held in captivity to aggregate in dense clumps in corners and along the walls of tanks [14], which makes it difficult to feed them effectively and wastes floor space. Another has focused on recirculating systems [27], as these present the possibility of controlling the animal's environment in ways that facilitate out-of-season roe production by precisely manipulating photoperiod and temperature [68, 60].

The first step toward commercial sea urchin culture in the Eastern Adriatic was taken in the summer of 2002 by the senior author and private associates in Dubrovnik. An underwater corral—dubbed *Ježeva kućica*, after the popular children's book authored by Branko Ćopić—installed at 8 m depth in Uvala Budima (about 40 km north of Dubrovnik) was stocked with 2.000 adult speciment of *P. lividus* and several hundred of *Sphaerechinus granularis*.

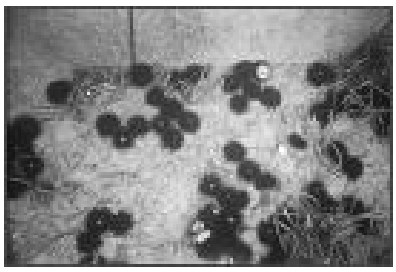

Fig. 2. Ježeva kućica, an urchin corral at 8 m in Uvala Budina
Slika 2. Kondicioniranje ježinaca u Uvali Budima Izvor: Nick Starešinić

The goals were simple: to gain experience with containment design and handling the animals, observe their behavior in captivity, and evaluate growth, mortality, and feeding. The quickest route to commercialization of sea urchin now seems to be 'bulking'—that is, out-of-season gonad enhancement—of natural stock. This is analogous to the way that Croatia's successful tuna-ranching industry operates, but in this case Croatian divers trained in the proper harvesting technique would be paid by a producer to deliver urchins to bulking stations set up at locations along the coast and on the islands. There, the animals would be contained in a controlled system and, over a period of 2 to 3 months, fed a diet that enhances their roe to market quality.

Domestic Market

Domaće tržište

Despite the quality of urchins found in the Adriatic, there essentially is no domestic market for urchin roe in Croatia. *Why?* Croatia is geographically a Mediterranean country, but the national eating habits are decidedly Continental: Croatians consume much more beer than red wine; much more meat than fish; much more butter than olive oil; and pork rinds instead of sea urchin! Few Croatians—even along the coast—admit to having ever eaten sea urchin; and many who have tried it profess not to like it. Further, of the few Croatians who *do* eat sea urchins, none eats them when they are at their best, at the peak of the natural season: late January – early March. It's just not part of the culture.

Fig. 3. Ripe roe of urchin from Lumbarda, Korčula
Slika 3. Ikra ježinca, Lumbarda, Korčula (Đ. Montana)

Even if sea urchins were to become popular in Croatia, disposable personal income generally is very low, while sea urchin is a high-priced luxury item that would not be accommodated on a regular basis by most family's food budgets.

Tourists

Turistička ponuda

Table 2. Croatian Foreign Tourists Arrivals (source: DZS, 2001.-2003.)
Tablica 2. Posjećenost inozemnih turista u Hrvatskoj (izvor: DZS, 2001.-2003)

	2001.	2002.	2003.
Italy	1.059.810	1.099.427	1.188.385
France	74.719	134.708	219.126
Spain	19.692	26.022	43.456
Japan	12.565	15.340	15.546
Others	5.377.431	5.668.848	5.914.170
Total	6.544.217	6.944.345	7.408.593

Tourists who may be expected to eat sea urchins during summer holidays in Croatia come from traditional Mediterranean countries—mainly Italy and France—and also from Japan. By far, the largest number of these is

from Italy (Table II), a country in which sea urchin is prized as a seafood delicacy. But Italians tourists—most of whom visit Istria—have become very accustomed to collecting their own sea urchins directly from the sea. As anyone who talks with them knows, they are very happily surprised to see the sea-bottom carpeted with 'free' sea urchins. It is not at all uncommon to see vacationing Italians on Lokrum snacking on sea urchins they have pried from the rocky bottom. Without effective policing of this resource, it thus seems highly unlikely that Italian visitors would be willing to spend as much as € 1 for a single fresh sea urchin in a seafood restaurant when they can serve themselves for free along Croatia's littoral.

The numbers of Japanese tourists yet are very small (Table II), but a niche market eventually may prove profitable for exclusive, small-scale producers who cater to their particular culinary tastes. (Of note, the 2005 World Exposition in Japan offers an excellent opportunity for Croatia to promote the quality its seafood in a nation that annually consumes about 70 kg of seafood per capita and is the largest market for sea urchins).

A very informal survey of Dubrovnik restaurant owners with whom the senior author is acquainted suggests that they want to offer sea urchin on their menus as a premium seafood product. They believe they can sell it, fresh and opened, for a per-piece price higher than that of oysters, which in the summer of 2003 sold in Dubrovnik for 5 – 7 Kn (€ 0,65 – 0,80) each. (For comparison, street-side vendors in Sardegna sold 12 opened sea urchins during the 2003 season for € 2 – 3.) This is their professional "feel" for the potential market, but is not based on any data that would satisfy a serious investor.

Export

Izvoz

The export potential of sea urchins best is summarized by noting that the world market for urchin roe is on the order of € 450 million annually. Most of this, by far, is owed to Japan [59, 71].

Japanese consumers are **especially** conscious of quality: They demand high quality in all of their products and are willing to pay for it. They much prefer urchin species harvested in their own waters but, as mentioned earlier, sea urchins from California is highly esteemed and fetches very attractive prices. Mediterranean sea urchin, on the other hand, essentially is unknown to Japanese consumers (Y. Yokota, Aichi Prefectural University, Aichi, pers. comm.). The key question thus is: Is the taste, texture, size, and color of P. lividus ikra acceptable to the Japanese palate? The senior author asked this question of three Japanese, two researchers in Japan who have tasted sea urchin in Italy, and the Japanese wife of an American friend resident in northern Sardegna. The answer of each is "HAI!" ("Yes!")—but with two very important qualifications. First, one of our Japanese colleagues stresses—and very rightly so—that although he believes the taste and general presentation will be acceptable, this personal observation is not a substitute for the hard market data on which any serious business decision must be based.

Second, as another points out (T. Unuma, National Research Institute of Aquaculture, Nansei, *pers. comm.*), quality control is very low: One sea urchin may contain excellent roe; and the next three or four may be so poor as to be worthless. Send the Japanese market just one bad shipment of any product at all and you may be marked for life as an undesirable commercial partner! Exporters from the northeast USA state of Maine learned this lesson the hard way. Urchins shipped from Maine initially were well received in Japan, but when Maine collectors began to expand their shipments rapidly, quality control decreased and, as a result, the entire state received a reputation for poor quality sea urchins; and even though quality since has improved significantly, prices for their product remain as much as 20% below those from California.

Market Bottom-line: The domestic market for sea urchin is insignificant in Croatia. The tourist market indeed may be profitable, but likely will require investment in market development. This will help stimulate the export market by introducing tourists from sea urchin-eating countries to the Croatian product. The export market is the target. Early market development should focus on penetrating Mediterranean countries, with trial shipments to Tokyo Chuo **ONLY** after quality has been insured.

Cephalopods

Glavonošci

General

Mollusc culture currently is based on raising mussels and oysters, but culture of cephalopods—squid, octopi, and cuttlefish—has attracted growing interest as a means of supplying traditional markets in Asia and Mediterranean Europe as the catch from natural stocks declines [6, 31, 40]. Several edible cephalopods indeed share features that make them especially attractive candidates for commercial culture. Among these are: a relatively short life-cycle, high fecundity, absence of a true larval stage, very rapid growth, and high food-conversion efficiencies [7, 8, 5]. Under optimal culture conditions, for example, the squid *Sepioteuthis lessoniana* can reach 600 g in only 4 months [40]; and some octopods can attain 2 - 3 kg in 6 - 8 months [33], among the fastest recorded growth rate for any marine macro-invertebrate. (In comparison, it takes roughly 18 – 22 months to raise seabass to something under one-half kilogram.)

Further, from the nutritional standpoint, cephalopods are as much as 95% protein (on a dry-weight basis), and 85% of the fresh mass of some species is edible tissue [28].

There currently are, of course, some limitations to large-scale cephalopod mariculture. Cephalopods are

carnivores that generally require live food during critical stages of development, the dependable supply of which yet is to be satisfactorily solved. Many species also are particularly susceptible to mortality from transport, fluctuations in temperature, water-quality changes, skin damage, and cannibalism [28, 50].

Some squid, nevertheless, have been reared successfully in captivity [29, 31]. In particular, *S. lessoniana*, an important commercial species in Japan [57] and Thailand, has proven well suited to the culture environment because of the large size of their hatchlings, tolerance to handling and confinement, short life span, and rapid growth rate [40, 41, 23]. *S. lessoniana*, in fact, has been cultured successfully on a small scale through seven consecutive generations at the National Resource Center for Cephalopods (NRCC) in Galveston, Texas [69]. There currently is, however, no commercial-scale culture of this promising species [56, 34, 48, 46]. Two cephalopods found in Croatian waters that have commercial potential are the cuttlefish (*Sepia officianalis*) and the common octopus (*Octopus vulgaris*). These are described briefly below.

Cuttlefish

Sipa

Biology

Biologija

Those outside of the cuttlefish research community often are surprised to learn that there is a broad and mature literature on this species, including ample data on its growth, development, reproduction, feeding, nutritional composition, physiology, and behavior. This body of work has documented basic features of cuttlefish biology that make it a suitable candidate for mariculture, including the relatively large size and voraciousness of the hatchlings, rapid growth to market size, a short life span, relatively easy spawning in captivity, tolerance to crowding, and admirable resistance to disease. They also tolerate a wide range of temperatures (13 – 25 °C) and accept a diet of various fish and crustaceans, alive or dead.

This basic research has laid a firm foundation for advancing development of the technology upon which commercial cuttlefish production depends.

Technology

Tehnologija

The European cuttlefish, *Sepia officinalis*, is one of the most easily cultured of all cephalopods [51, 3, 21, 22] and has great potential as a commercial mariculture species. Adult cuttlefish raised in captivity reach a market size of 500 g to 1.5 kg in about 10 months at 20 – 24 °C. (The *cuttlefish's* tropical Asian cousin, *S. pharaonis*, the pharaoh cuttlefish, is much larger and grows much faster, reaching a maximum adult size of 3 kg in only about 7 months on a diet of frozen shrimp [44].)

Over the past two decades, the National Resource Center for Cephalopods in Galveston and its collaborators have achieved impressive results in developing a suite of biological and engineering techniques needed to raise disease-free cuttlefish in closed seawater systems. The NRCC's current stock, in fact, is the *thirteenth* consecutive generation reared in the lab (NRCC, unpublished data). Such a claim can be made for very few—if, indeed, any other—cultured marine species.

Fig. 4. *S. officinalis* under culture at the NRCC, Galveston
Slika 4. Uzgoj sipe, S. officinalis u Galvestonu
Izvor: L.S. Walsh

The NRCC's main mission is to supply the biomedical community around the world with the 'giant axons' and the curiously human-like eyes of cephalopods, but fundamental advances made at the lab have very clear application to commercializing cuttlefish culture for the much larger edible seafood market.

Their work—as well as that of groups in Canada, France, and Portugal—have identified two main factors that limit mass culture of cuttlefish. Foremost of these is the requirement of early stages for live food, preferably crustaceans, such as live mysids or very young shrimp [53, 66, 15, 38]. Young sipa can be reared on brine shrimp (*Artemia*)—natural or enriched—or small fish (*Gambusia* sp.) for at least six weeks after hatching, but their growth is much slower and their survival is not nearly as high as those fed mysids [12]. The commercial challenge, then, is to provide a dependable supply of mysids at an acceptable cost.

Another limitation is the population density at which the animals may be cultured [70]. Forsythe et al. [20] documented decreased growth rates in high-density cuttlefish cultures at 25° C when compared to low-density groups at the same temperature. Food consumption was similar in both groups, so it is likely that animals at high-density expended a larger portion of their available energy in agonistic interactions, and therefore had less to devote to tissue growth.

Low densities may be acceptable when the final product is destined for the biomedical research community; but production for the seafood market will demand higher stocking loads. Overcoming this limitation requires modifications of standard tank designs, changes

in the routine application of feed, and perhaps—over the longer term—stock domestication.

Domestic Market
Domaće tržište

A large segment of the Croatian populace is familiar with cuttlefish as prepared in the popular seafood dish *Black Risotto*. Thus, although not a close rival to any meat product, the domestic market for cuttlefish may be important enough to warrant considering commercial production. The largest item in Croatia's edible seafood import budget, in fact, is the tariff category that combines "dried, salted, and frozen cuttlefish and squid". In 1998, this amounted to about 3.270 MT of product worth about € 8.5 million [16].

Fresh cuttlefish is available domestically mainly in the spring—along the coast there is a saying: *u pol marča, sipa i komarča*—and generally is scare or absent at other times of the year. There are no systematic data on prices, but anecdotal information gathered in the Dubrovnik and Split areas by the senior author suggests market prices range between Kn 50 – 80 (€ 6.75 – 11.85) per kg, with typical animals being about 500 g.

It is noteworthy that the Croatian housewife who prepares squid or cutttlefish at home usually starts by opening a box of frozen squid caught off California, or cuttlefish fished off Morocco. Thus, year-around domestic production of cuttlefish would contribute to reducing foreign food imports, a pressing goal for Croatia.

Tourists
Turistička ponuda

In the absence of data on tourist seafood consumption in Croatia [62], anecdotal information suggests that cuttlefish dishes—especially *risotto*—are very popular with foreign tourists at Croatian restaurants. Thus, the same conclusion reached immediately above for the domestic market seems reasonable here: Mariculture may be a profitable way to supply fresh cuttlefish to Croatia's growing coastal tourist market.

Export
Izvoz

As with other commercial fishery resources, cuttlefish stocks are declining, but foreign markets presently do not appear to be so seriously under-supplied that export of cuttlefish cultured in Croatia would be an immediately attractive option. If, however, cuttlefish mariculture is developed, promotion of a high-quality, branded product from Croatia might open the large markets in traditional cuttlefish-consuming Mediterranean countries, especially Spain, France, Greece, and Italy.

Market Bottom-line: There seem to be promising domestic and tourist markets to support at least small-scale cuttlefish commercialization in Croatia. Should this prove profitable, there would be a reasonable basis for exploring the feasibility of exporting to the major Mediterranean markets.

Octopus
Hobotnica

Biology
Biologija

The common octopus, *O. vulgaris*, is distributed worldwide in shallow temperate and tropical waters and has been the subject of a good deal of basic research [55]; but basic knowledge of its early stages still is rather scarce. Briefly, after releasing eggs the female tends them until they hatch, a period that might take from one to two months, depending on water temperature [4]. During this period the female will not leave the den even to feed, but aerates and cleans the eggs with her arms day and night. This tremendous level of dedication ensures that nearly all the eggs will hatch, although the diligent female pays the 'ultimate price'—that is, it dies—soon after the last hatchling emerges. Newly-hatched octopi are termed *paralarvae*—roughly, 'false larvae'—because, unlike other molluscs, cephalopods do not have a true larval phase. The hatchling octopus thus is a miniature version of the adult and—with the exception of reproducing—are able to do almost everything an adult can, such as swim, capture prey, expand and contract their chromatophores for purposes of camouflage, and release ink.

Despite the large size attained by adult *O. vulgaris*, their young paralarvae are small and live as members of the plankton for a period that lasts nearly 2 months at 21°C [67]. This paralarval phase is the most vulnerable in its life cycle, and so the one that poses the biggest constraint to its mariculture [33]. It thus is a natural focus for applied research.

Technology
Tehnologija

Many different octopus species have been cultured through their entire life cycle, with most research having been dedicated to those species with large eggs and hatchlings, such as *O. joubini, O. briareus, O. spogmaya, O. bimaculoides,* and *O. digueti.* The advantages of culturing these species is that, owing to their large eggs and lack of a planktonic stage, their hatchlings are more robust, capable of feeding immediately on larger prey, and consequently have relatively faster growth rates [30]. With a short life cycle (12-18 months), rapid growth (up to 13% body weight d^{-1}), and high food conversion (15% - 43%) [43, 42, 25], O. vulgaris has received considerable attention as a suitable species for culture.

The major limiting factor to commercial production of octopus is culture of its planktonic paralarvae. Failure of first-feeding and starvation are among the primary causes of mortality in planktonic cephalopod hatchlings maintained in culture [28]. Some success with experimental paralarval culture of this species has been achieved, but problems of inadequate diets and mortality remain [49]. Recent studies with squid hatchlings have demonstrated that both good survival and growth are achieved through new culture techniques that have been adapted successfully to other species, including *O. vulgaris* [64, 65]. This is an important step that advances the realization of commercial-scale octopus hatchery production.

Fig. 5. Dorsal view of 22- days old O. Vulgaris paralarva raised in the laboratory

Slika 5. 22-dana star laboratorijski uzorak ličinke hobotnice O. vulgaris

Izvor: E.A.G. Vidal

Other research addresses the most efficient way to fatten under-sized octopi collected in the wild. These are fed by-catch—mainly 'trash' fish, crabs, and molluscs that otherwise are discarded by commercial fishermen—until they reach 800 g to 1 kg. The main issue that arises here relates to the aggressive territoriality typical of adult *O. vulgaris*. Reducing the negative effects that this behavior has on growth and survival requires containment structures that separate individuals without making routine feeding, maintenance, and harvesting unmanageable.

A research group in Asturias (northwestern Spain) appears to be most advanced in this area [54]. Using rectangular cages in which sections of plastic tubes were placed as refuges, they stocked wild octopus of about 1 kg each at a density of 10 – 12 kg/m^2. After about 3 months, during which time they were fed a diet of mixed by-catch, they reached an average size of 3.5 kg each, with survival no lower than 80%.

Market

Tržište

Domestic Market & Tourists

Domaće tržište/Turistička potražnja

For the sake of brevity, the Domestic and Tourist segments can be combined, and it can be noted simply that the same comments made above for cuttlefish generally apply to the market for octopus. Fresh octopus can be found in markets along the Central and Southern coast throughout the year, though during the tourist season the catch usually by-passes the seafood markets altogether and goes directly to restaurants.

As with cuttlefish, there are no systematic price data; but, depending on the time of year, market prices range between Kn 40 – 60 (roughly € 5.60 – 8.40) per kg. Most animals appear to be between 800 g and 1 kg, though both smaller and somewhat larger individuals appear frequently.

The tentative conclusion is that there may be enough combined domestic and tourist demand for octopus in Croatia to justify serious evaluation of its mariculture production potential.

Export

Izvoz

No detailed analysis of the export market is attempted here. Suffice it to note that, if Croatia produces a high-quality product, Mediterranean countries such as Spain (statistically the largest consumer of octopus in the area), Greece, and Italy represent attractive year-around markets. Prices vary in each of these countries, especially seasonally, and in many cases they exceed those found in Croatia. As an example, in Greece a fresh, one-kilo octopus can sell to the restaurant trade for € 10/kg.

Market Bottom-line: The same conclusions reached above for cuttlefish apply to octopus: Croatian domestic and tourist markets appear to be sufficiently large to justify at least small-scale commercial octopus production. Should this be profitable, the countries of the European Mediterranean offer interesting export opportunities.

Summary

Zaključak

In the early 1980s Croatian marine scientists—especially Dr. Ivan Katavić (*Director, Fisheries and Mariculture, Ministry of Agriculture and Forestry*), Mr. Tomislav Vodopija (Cenmar, Zadar), Dr. Emin Teskeređžić (Director of Aquaculture dept., Institute "Ruđer Bošković"), and Mr. Željko Filić (*Director, MARIMIRNA, Rovinj*)—made important technical and practical contributions to the development of fish cage culture in the Mediterranean. Twenty years later, this has evolved into a mature, multi-million-euro industry. But with Greece producing over 100.000 MT annually, Croatia's industry remains small (less than 4.000 MT) and finds itself in the particularly unenviable position of relying almost exclusively on importing the two most important factors of production, seed and feed.

The authors believe that all three species examined briefly here have commercial potential for Croatia; but if they are developed according to the seabass development model", these "new" species will become "old" species before the industry can say "*Paracentrotus lividus*" three times quickly. Other countries are aware of the economic opportunities these particular species present and are pressing ahead with their commercialization.

As just one of many examples the authors could cite, the vibrant and aggressive Irish aquaculture industry harvested 5 MT of out-planted sea urchins in 2001, and their plan is to increase this to 50 - 80 MT annually over the next 3 – 4 years.

To get to the point at which Croatian mariculture is competitive requires action. In addition to thoroughly studying the domestic, tourist, and export markets for cuttlefish, sea urchin and octopus—treated only in very nominal terms here—each species deserves quick action on the technical front.

Cuttlefish Action: Of the three, cuttlefish can be commercialized the fastest. The pieces of the puzzle are on the table. The next step for Croatia is to apply the best available technology to build and operate a small-scale pilot facility, the immediate goal of which is to collect the data needed to evaluate the economic feasibility of cuttlefish production under local conditions.

Sea Urchin Action: The next step is to evaluate the economics of bulking wild urchins under Croatian conditions using the best available technology. This centers on feed trials that test at least one of several published feed formulations, a promising experimental

feed from the US, and a diet of macroalgae that might 'polish' the final product's taste to high market standards.

Octopus Action: Promising advances in octopus paralarvae culture have been made very recently in Brasil and, in the autumn of 2003, were transferred to applied mariculture research teams in Spain and South Africa. These same techniques should be transferred to the Croatian research community to insure that the domestic industry is prepared to take full advantage of octopus culture when it becomes a commercial reality.

If successful, domestically produced octopus, cuttlefish, and the sweet-tasting, bright red roe of Croatian urchins will find ready acceptance—just like Croatian tuna—by the discerning palates of Japanese and French consumers, as well as by gourmets around the world who appreciate the special flavor of top-quality seafood. And the economy will benefit from new products that enhance the variety of fresh seafood offered to the growing number of tourists to the Croatian Adriatic, increase export earnings, and support coastal development, including year-around employment in core production and down-stream processing sectors [61].

Acknowledgements

Zahvala

The original version of this paper was prepared for, and presented at, the October 2003 workshop in Kotor, Montenegro, organized by the Releasing Development Potential at the Coast (RDPC) project, sponsored by the Norwegian National Technical University (NTNU, Trondheim) and generously supported by the Norwegian government.

The authors wish to thank Dr. Oddmund Otterstad (NTNU, Trondheim) for his invitation to, and support during, the Kotor workshop; Ana Popović (Dubrovnik), for key research assistance and helpful suggestions; and especially Tatjana Nikić for critical support during early drafts of this paper.

Literature

Literatura

[1] Anonymous. 2002. Laboratory claims bluefin breeding breakthrough. FIS.com, World News (Japan, 05 July 2002). http://www.fis.com

[2] Anonymous. 2004. Greek Pisiculture. http://www.greekproducts.com/b2b/pisciculture.html

[3] Boletzky, S. von. 1979. Growth and life-span of Sepia officinalis under artificial conditons (Mollusca Cephalopoda). Rapp. Comm. Int. Mer. Medit. 25/26,: 159-168.

[4] Boletzky, S. von. 1987. Juvenile behaviour. In: Cephalopd LifeCycles, 2, Boyle P.R., (ed.), Academic Press, London, p. 45-60.

[5] Boletzky, S. von. 1989. Elevage de Cephalopodes en aquarium: acquis recents. Bull. Soc. Zool. Fr. 114: 57-66.

[6] Boletzky, S. von. and R.T. Hanlon. 1983. A review of the laboratory maintenance rearing and culture of cephalopod molluscs. Mem. Nat. Mus. Victoria 44: 147-187.

[7] Boyle, P. R. (ed.) 1983. Cephalopod Life Cycles, vol. I Academic Press, London, p. 1-475.

[8] Boyle, P.R.(ed.) 1987. Cephalopod Life Cycles, vol. II Academic Press, London, p. 1-441.

[9] Cabello, L. 2001. Sistemas de manejo, mantenimiento y consideraciones operacionales. In: J. Muir and B. Basurco (eds.), Advanced Course in Mediterranean Offshore Mariculture. Instituto Agronomico Mediterraneo de Zaragoza.

[10] Cameron, R.T. 2002. Sea urchin developmental genetics and culture. In: Y. Yokota, V. Matranga, Z. Smolenicka (eds.), The Sea Urchin: From Basic Biology to Aquaculture. Swets & Zeitlinger, Lisse. pp. 31-36.

[11] de Jong-Westman, M., P.-Y. Quian, B.E March, and T.H. Carefoot. 1995. Artificial diets in sea urchin culture: effects of dietary protein level and other additives on egg quality, larval morphometrics, and larval survival in the green sea urchin, Strongylocentrotus droebachiensis. Can. J. Zool. 73:2080-2090.

[12] DeRusha, R.H., J.H. Forsythe, F.P. DiMarco, and R.T. Hanlon. 1989. Alternative diets for maintaining and rearing cephalopods in captivity. Lab. Anim. Sci. 4: 306-312.

[13] Devin, M.G. 2001. Mass translocation of low-quality deepwater sea urchins to overfished shallow-water sites. In: L. Hiemstra (ed.), Proc. Sea Urchin Culture Workshop, Nanaimo, B.C., p. 17.

[14] Devin, M.G. 2002. Land-based echinoculture: A novel system to culture adult sea urchins. In: Y. Yokota, V. Matranga, Z. Smolenicka (eds.), The Sea Urchin: From Basic Biology to Aquaculture. Swets & Zeitlinger, Lisse. pp. 145-159.

[15] Domingues, P.M., P.E. Turk, J.P. Andrade, and P.G. Lee. 1998. Pilot-scale peroduction of mysid shrimp in a static water system. Aquaculture International 6: 387-402.

[16] Dujmušić, A. 2000. Hrvatsko Ribarstvo Ispod Površine. (Croatian Fisheries Under the Surface) Rabus Media, Zagreb. (215 pp.) ISBN 953-98265-0-0

[17] DZS (Central Bureau of Statistics, Republic of Croatia) 2003. Statistical Information for 2003

[18] Forsythe, J.W. and R.T. Hanlon. 1988. Effect of temperature on laboratory growth, reproduction and life span of Octopus bimaculoides. Mar. Biol. 98: 369-379.

[19] Forsythe, J.W. and R.B. Toll. 1991. Clarification of the western Atlantic Ocean pygmy octopus complex: The identity and life history of Octopus joubini (Cephalopoda: Octopodinae). Bull. Mar. Sci. 49: 151-169.

[20] Forsythe J, Lee P, Walsh L and Clark T. 2002. The effects of crowding on growth of the European cuttlefish, Sepia officinalis Linnaeus, 1758 reared at two temperatures. J. Exp. Mar. Biol. Ecol. 269:173-185.

[21] Forsythe, J.W., R.T. Hanlon, and R.H. DeRusha. 1991. Pilot large-scale culture of Sepia in biomedical research. In: The Cuttlefish: Acta I. Int. Symp. Cuttlefish Sepia, pp. 313-323. Boucaud-Camou E (ed.), Centre de Publications de l'Universite de Caen, France.

[22] Forsythe, J. W., R. H. Derusha, and R. T. Hanlon. 1994. Growth, reproduction and life span of Sepia officinalis (Cephalopoda:Mollusca) cultured through seven consecutive generations. J. Zool. (Lond.). 233:175-192.

[23] Forsythe, J.W., L.S. Walsh, P.E. Turk, and P.G. Lee. 2001. Impact of temperature on juvenile growth and age at first egg-laying of the Pacific reef squid, Sepioteuthis lessoniana, reared in captivity. Mar. Biol. 138: 103-112.

[24] Frantzis, A. and A. Gremare. 1992. Ingestion, absorption and growth rates of Paracentrotus lividus (Echinodermata: Echinoidea) fed different macrophytes. Mar. Ecol. Prog. Ser. 95:169-183.

[25] Garcia Garcia, B., Aguado, F. 2002. Influence of diet on on-growing and nutrient utilization in the common octopus (Octopus vulgaris). Aquaculture 211, 171-182.

[26] Glamuzina, B., J. Jug Dujaković, and I. Katavić. 1989. Preliminary studies on reproduction and larval rearing of common dentex, Denrex dentex (Linnaeus, 1758). Aquaculture, 77: 75-84.

[27] Grosjean, P., Spirlet, C., Gosselin, P., Vaïtilingon, D., Jangoux, M. 1998. Land-based, closed-cycle echiniculture of Paracentrotus lividus (Lamarck) (Echinoidea: Echinodermata): a long-term experiment at a pilot scale. J. Shellfish Res. 17: 1523-1531.

[28] Hanlon, R.T. 1987. Mariculture. In: P.R. Boyle (ed.), Cephalopod Life Cycles, v. II. Academic Press, London,, pp. 291-305.

[29] Hanlon, R.T. 1990. Maintenance, rearing, and culture of teuthoid and sepiod squids. In: D.L. Gilbert, W.J. Adelman, J.M. Arnold (eds.), Squid as Experimental Animals. Plenum. New York, pp. 35-62.

[30] Hanlon, R.T. and J.W. Forsythe. 1985. Advances in the laboratory culture of octopuses for biomedical research. Lab. Anim. Sci. 35: 33-40.

[31] Hanlon, R.T., P.E. Turk, and P.G. Lee. 1991. Squid and cuttlefish mariculture: An updated perspective. J. Cephalopod Biology 2: 31-40.

[32] Hooper, R.G. 2001. Progress in sea urchin enhancement, ranching, and aquaculture in Newfoundland. In: L. Hiemstra (ed.), Proc. Sea Urchin Culture Workshop, Nanaimo, B.C., p. 11-13.

[33] Iglesias, J., F.J. Sanchez, and J.J. Otero. 1997. Primeras experiencias sobre el cultivo integral del pulpo (Octopus vulgaris Cuvier) en el Instituto Espanol de Oceanografia. in: J. de Costa, E. abellan, B. Garcia, A. Ortega, S. Zamora (eds.), Actas 6, Congreso Nacional de Acuicultura, Cartagena, pp. 221-226.

[34] Japan Sea Farming Fisheries Association (JSFFA). 1985. Farming Fisheries Seed Production, Procurement and Releasing Statistics for 1983. JSFFA Publication, Tokyo. 298 pp. (In Japanese)

[35] Katavić, I. and T. Vodopija. 2001. Razvojne mogućnosti marikulture u Republici Hrvatskoj. (Development possibilities for mariculture in the Republic of Croatia) Ribarstvo 59: 71 – 84.

[36] Keesing, J.K. and K.C. Hall. 1998. Review of harvests and status of world sea urchin fisheries points to opportunities for aquaculture. J. Shellfish Res. 17: 1597-1604.

[37] Kelly, M.S., C.C. Brodie, and J.D. McKenzie. 1998. Somatic and gonadal growth of the sea urchin Psammechinus millaris (Gmelin) maintained in polyculture with the Atlantic salmon. J. Shellfish Res. 17: 1557-1562.

[38] Koueta, N., E. Boucaud-Camou, B. Noel. 2002. Effect of enriched natural diet on survival and growth of juvenile cuttlefish Sepia officinalis L. Aquaculture 203: 293-310.

[39] Lawrence, J.M., S. Olave, R. Otaiza, A.L. Lawrence, and E. Bustos. 1997. Enhancement of gonad production in the sea urchin Loexechinus albus in Chile fed extruded diets. J. World Aquaculture Soc. 28: 91-96.

[40] Lee, P.G., P.E. Turk, W.T. Yang, and R.T. Hanlon. 1994. Biological characteristics and biomedical applications of the squid Sepioteuthis lessoniana cultured through multiple generation. Biol. Bull. (Woods Hole) 186: 328-341.

[41] Lee, P.G., L. Walsh, P.E. Turk, and F.P. DiMarco. 2000. Large-scale culture of loliginid squid, Sepioteuthis lessoniana. Proceedings from the Special Session on Mollusc Culture, Fifth Asian Fisheries Forum, Chiang Mai, Thailand 217-225.

[42] Mangold, K.M., 1983. Octopus vulgaris. In Boyle, P.R. (Ed.), Cephalopod Life Cycles, vol. 1. Academic Press, London, pp 335-364.

[43] Mangold, K.M., Boletzky, S.v., 1973. New data on reproductive biology and growth of Octopus vulgaris. Mar. Biol. 19,7-12.

[44] Minton, J.W., L. S. Walsh, P.G. Lee, and J.W. Forsythe. 2001. First multi-generation culture of tropical cuttlefish Sepia pharaonis. Aquaculture International. 9: 379-392.

[45] Murata, Y. and N. U. Sata. 2000. Isolation and structure of pulcherrimine, a novel bitter-tasting amino acid, from the sea urchin (Hemicentrotus pulcherrimus) ovaries. J. Ag. Food Chem. 48: 5557-5560.

[46] Nabhitabhata, J. 1995. Mass culture of cephalopods in Thailand. World Aquaculture 26(2), 25-29.

[47] Nabhitabhata, J. and P. Nilaphat. 1999. Life cycle of cultured pharaoh cuttlefish, Sepia Pharaonis

Ehrenberg, 1831. Phuket Marine Biological Center Special Publication 19(1), 25-40

[48] Nagata, W. D. and H. Hirata. 1986. Mariculture in Japan: past, present, and future prospectives. Mini Review Data File Fish. Res. 4: 1-38.

[49] Navarro J.C. and R. Villanueva. 2003. The fatty acid composition of Octopus vulgaris paralarvae reared with live and inert food: deviation from their natural fatty acid profile. Aquaculture. 219 : pp.613-631

[50] Oestmann D.J., J.M. Scimeca, J.W. Forsythe, R.T. Hanlon, and P.G. Lee. 1997. Special considerations for keeping cephalopods in laboratory facilities. Contemp. Topics Lab. Anim. Sci. 36(2):89-93.

[51] Pasqual, E. 1978. Crecimiento y alimentacion de tres generaciones de Sepia officinalis en cultivo. Invest. Pesq. 42: 421-442.

[52] Pantazis, P., M. S. Kelly, J.G. Connoly, and K.D. Black 2000. The effect of artificial diets on growth, lipid utilisation and gonad biochemistry of the adult Sea Urchin Psammechinus miliaris (Gmelin). J. Shellfish Res. 19 (2), 995-1001.

[53] Reitsma, L. and J.M. Neff. 1980. A recirculating artificial seawater system for the laboratory culture of Mysidopsis almyra (Crustacea: Pericaridea). Estuaries 3: 321 – 323.

[54] Rodriguez, C., J.F. Carrasco, and M. Rodriguez. 2001. Engorde de juveniles de pulpo (Octopus vulgaris, Cuvier 1797) en jaula. (manuscript)

[55] Roper, C.F.E., M. Sweeney, and C.E. Nauen. 1984. FAO Species Catalogue, Vol.3. Cephalopods of the World. FAO Fisheries Synopsis No. 125.

[56] Sato, H. and T. Tsuzaki. 1984. Seed production of Sepioteuthis lessoniana Lesson. Saibai (Sea Farming) 29: 20-23. (In Japanese)

[57] Segawa, S. 1987. Life history of the oval squid, Sepioteuthis lessoniana, in Kominato and adjacent waters central Honshu, Japan. J. Tokyo Univ. Fish. 74: 67-105.

[58] Skaramuca, B., V. Kožul, I. Katavić, N. Glavić, P. Tutman, L. Grubišić, and B. Glamuzina. 2000. Recent Advances on the Diversification of Marine Finfish Species in Croatia. CIHEAM/TECAM Workshop: 359 – 363.

[59] Sonu, S.C. 1995. The Japanese sea urchin market. National Oceanographic and Atmospheric Administration, Tech Memor 30, Southwest Region, National Marine Fisheries Services. Long Beach, California, 33 pp.

[60] Spirlet, C., P. Grosjean, and M. Jangoux, M. 2000. Optimization of gonad growth by manipulation of temperature and photoperiod in cultivated sea urchin, Paracentrotus lividus (Lamarck) (Echinodermata). Aquaculture 185: 85-99.

[61] Staresinic, N., B. Glamuzina, I. Jelčić, A. Benović, J. Lovrić, D. Ivušić, and A. Bratoš. 2001. Challenges for Croatian Mariculture in the 21st Century. Naše More 48 : 252 – 264.

[62] Staresinic, N. and A. Popović. 2004. The links between tourism and mariculture: The case of Croatia. XI World Congress of Rural Sociology. Trondheim, Norway, July 2004. (submitted)

[63] Unuma, T. 2002. Gonadal growth and its relationship to aquaculture in sea urchins. In: Y. Yokota, V. Matranga, Z. Smolenicka (eds.), The Sea Urchin: From Basic Biology to Aquaculture. Swets & Zeitlinger, Lisse. pp. 115-127.

[64] Vidal, E.A.G., F.P. DiMarco, J.H. Wormuth, and P.G. Lee. 2002a. Optimizing rearing conditions of hatchling loliginid squid. Mar. Biol. 140: 117-127.

[65] Vidal, E.A.G., F.P. DiMarco, J.H. Wormuth, and P.G. Lee. 2002b. Influence of temperature and food availability on survival, growth and yolk utilization in hatchling squid. Bull. Mar. Sci .71: 915-931

[66] Villanueva, R. 1994. Decapod crab zoeae as food for rearing cephalopod paralarvae. Aquaculture. 128 : pp.143-152

[67] Villanueva, R. 1995. Experimental rearing and growth of planktonic Octopus vulgaris from hatching to settlement. Canadian Journal of Fish. Aquat. Science. 52 : pp.2639-2650

[68] Walker, C.W. and Lesser, M.P. 1998. Manipulation of food and photoperiod promotes out-of-season gametogenesis in the green sea urchin, Strongylocentrotus droebachiensis: implications for aquaculture. Mar. Biol. 132: 663-676.

[69] Walsh, L. S., P. E. Turk, J. W. Forsythe, and P. G. Lee. 2002. Mariculture of the loliginid squid Sepioteuthis lessoniana through seven successive generations. Aquaculture 212: 245-262.

[70] Warnke, K. 1994. Some aspects of social interaction during feeding in Sepia officinalis (Mollusca: Cephalopoda) hatched and reared in the laboratory. Vie et Millieu 44: 125 – 131.

[71] Yokota, Y. 2002. Fishery and consumption of the sea urchin in Japan. In: Y. Yokota, V. Matranga, Z. Smolenicka (eds.), The Sea Urchin: From Basic Biology to Aquaculture. Swets & Zeitlinger, Lisse. pp. 129-138.

Rukopis primljen: 23.03.2004.