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SUMMARY – The continuous development of offshore aquaculture is increasing the need for new vessel, barge and work platform designs to support the operation of the large production cages and their mooring systems. Increasing distances from shore, the need for high speed access, the potential for difficult sea conditions and increasing demands on capacity and all-weather working all contribute to increasingly challenging design requirements. Designs are therefore changing, from simple skiffs of length up to 10 m, with inboard and outboard motors of moderate power (<100 hp), to larger specialized higher powered vessels with multipurpose objectives, including operation support, feeding, and live fish transport; to large working platforms or barges with a feed storage capacity of 400 t or more and possibilities of accommodating a work team to perform all operation and maintenance activities. This chapter describes various recent designs demonstrating this evolution.

Key words: Mariculture, vessels, barges, management.

***RESUME –** "Mariculture en mer ouverte : Bateaux de travail". Le développement continu de l'aquaculture de haute mer augmente les besoins en nouveaux bateaux, barges et plates-formes de travail, servant à accomplir les tâches relatives à une importante production et d'apporter un soutien au système de mouillage. L'éloignement des sites d'implantation par rapport au rivage, le besoin d'accéder rapidement aux sites, le potentiel de résistance du matériel à des conditions difficiles, la demande croissante en capacité à travailler par tous les temps contribuent à augmenter le besoin incessant en modernisation et amélioration des équipements. Les techniques changent, de simples hors-bord de moins de 10 mètres, on est passé à des bateaux très puissants, conçus pour plusieurs activités, y compris déplacer les cages, alimenter les animaux, les transporter ; ou à de vastes plates-formes ou barges ayant une capacité de stockage en aliment de 400 tonnes ou plus, et des possibilités d'hébergement permettant à une équipe de garde d'assurer les opérations journalières et la maintenance du site. Cet article décrit les récentes mises au point illustrant cette évolution.*

***Mots-clés :** Mariculture, bateaux, barges, gestion.*

Introduction

The necessity of carrying out various management and husbandry operations away from shorebases, the exclusion of working platforms from many current cage designs, and the need to maintain open sea aquaculture installations, make workboats and auxiliary platforms amongst the most essential elements for the development of the offshore industry.

As in other system components, the key to the choice of workboat or operating platform is heavily influenced by not only the required tasks, but also by wave climate, in both prevailing (common or normal) and storm conditions. Choice is likely to be a compromise between conflicting factors, with budgets often being a critical factor. However, their correct choice is vital, as unreliable equipment will be very costly and possibly dangerous, and systems with restricted capacity may be unable to cope with marginal conditions, thus denying opportunities for feeding, harvest, or critical maintenance or repair. Some of the key background factors are outlined in Table 1.

Table 1. Factors in defining needs for work vessels and systems in offshore aquaculture

Factor	Features	Issues to consider
Boat operations	Feeding, grading, harvesting, net changing, diver support, towing, moorings, etc.	Feed quantities in tonnes, cranes, beach ramp, feed cannon, winches, grading table, compressor.
Shore-base	Beach, pier or harbou, secure all weather mooring, floating pontoon, haul-out.	Which option is available influences the boat design, ramp or crane, twin engine, etc.
Wave climate	Boat size, stability – Carrying capacity, beach operation, cage damage alongside.	Displacement planning hull, material, fenders, bulkheads and hatches, safety equipment.
Site distance	Boat endurance, interim wave climate, security and night work, certification.	Engine(s) choice, fuel capacity, lights, radios and radar, bunks and cooking facilities.
Crew, insurance and safety	Boat and crew certification, annual maintenance requirements, crane operation.	Local slipways or dry docks, training, stability trials, crane cut-outs, gas detector, etc.

Options for use

Basic service boats

For aquaculture operations GRP, steel and aluminium boats are probably most common, though traditional timber boats, and modern types such as inflatable, moulded nylon/polystyrene tenders, etc. are also used. As well as conventional vessels, it is common to use various barges, work platforms, etc., sized basically on their load-carrying capacity. These may be steel, timber or GRP, with additional hollow or polystyrene floats, if required. Such boats are of course particularly important for offshore cage systems, but may also be used, e.g., for enclosure systems, and for onshore tank systems to gain access to the seaward side of pump stations, to monitor waste discharges, etc.

Apart from cost/durability and seaworthiness, particular care should be taken to ensure that service boats and platforms are stable under the expected loads and working conditions. Heavy deck cargo in particular should not be loaded too high above the waterline of the vessel.

Many different types of small boats are used; much depends on local availability, custom, etc. Load-carrying is usually limited to 2 to 3 staff plus perhaps 100 to 200 kg of feed, harvested stock, gear, etc. Conventional single-hulled moulded GRP dinghies, 4 to 5 m length, with oars and small outboards (3 to 10 hp) are common and are reasonably versatile. Flat-bottomed aluminium boats (e.g., ex-military or similar type) are also common. For intermediate – scale tasks, carrying staff, loads of 500 to 2000 kg, towing small floats, cages, small barges, etc., a range of general-purpose work boats is employed, including:

(i) 5 to 10 m GRP open or partially-closed decked boats with or without forward cabin, and 10 to 50 hp inboard diesel engines, good for towing and general purpose duties in a range of sea conditions. Those with variable-pitch propellors are particularly versatile.

(ii) Higher speed planing GRP cathedral-hulled open-decked boats (e.g., "Dell Quay Dory", 5 to 8 m length, with inboard/outboard or outboard engines of 25 to 60 hp, good for rapid access and reasonable carrying capacity, in fair to moderate sea conditions. These are either open or have a small forward cabin.

(iii) Landing craft type boats, steel or GRP, square ended, with flat-bottomed hull, forward loading ramp, aft or side wheelhouse, inboard or outboard motors, 30 to 80 hp, typically 8 to 12 metres by 2 to 3 m breadth, with good carrying capacity, with some designs capable of taking on loaded vehicles, suitable for fair to moderate sea conditions.

Many of these boats can also be fitted with ancillary devices, such as hoists, hydraulic haulers or winches, rollers for handling cage nets or anchor ropes, deck pumps, net washers, and in some cases, small live holds or ice holds for stock. For larger-scale operations, a number of more specialized vessels have been used or developed, much depending on the type of work required, the capacity and scale of loads, etc. For laying or lifting anchors, heavy-duty towing jobs, bulk lifting, e.g., of nets from large offshore cages, transport of stock, conventional fishing boats are often used, e.g., decked or partially decked, GRP, timber or steel, 15 to 30 m length, with 100 to 500 hp inboard engines and suitable haulers, power blocks, holds, etc. Forward-wheelhouse types, with a relatively flat and spacious rear deck are probably the most convenient. Other vessels have included small ferries and larger landing craft.

Purpose designed vessels

For inshore and offshore shellfish culture, a range of vessels has been developed, originally as modifications of traditional fishing vessels, but increasingly designed for specific operational objectives, particularly for laying and lifting ropes, cleaning, grading and transferring stock, and for carrying harvested stock to onshore facilities. These are usually self-powered, or may be based on barge designs, with good stability and high lifting and carrying capacity as key features. Water pumps and pressure hose systems are common for cleaning. In inshore areas, service vessels or amphibious craft have been developed for similar purposes, with additional functions such as bed cleaning or conditioning using high pressure water and/or air systems, or mechanical devices. For both inshore and offshore systems, stock depuration is usually carried out on shore.

For fish culture, a number of vessels has been built purposely for handling large cages and nets, moving large quantities of stock, moving and distributing large quantities of feed, and handling and storing/icing equivalent amounts of harvested stock. Typically these are steel or GRP, 12 to 20 m length, 4 to 6 m beam, 200 to 500 hp inboard diesels, with variable pitch propellor, with forward wheelhouse, normal radio and electronic equipment, crew accommodation, flat rear deck and square stern, with overhead gantry and power block, wet well hold, ordinary and refrigerated hold, provisions for deck-mounted storage, feed distribution pump, high-pressure net washer, auxiliary generator, good deck lights, etc. These vessels, though expensive, are usually justified by their versatility and efficiency in servicing cage systems in all weather conditions. Selected examples are described in the next sections.

Barges and work platforms

A range of flat-decked craft has been brought into service for inshore and offshore aquaculture, either for shorter-term objectives such as the placing of moorings, or for routine operations such as net changing, shellfish stock cleaning, fish or shellfish grading and harvesting, fish feeding. In some cases, accommodation and other work facilities may also be incorporated. Such barges or work platforms may be adaptations of existing vessels, either self-powered or towed and moored into place, often carrying generators, cranes and other service equipment on deck, or may be specialized and purpose built designs, with service equipment specially built in. More traditional systems are typically of timber hulled or steel pontoon construction, usually with inbuilt buoyancy float units. Standard timber or steel cage structures are often modified for such purposes. For better stability in more exposed conditions barges or work platforms are usually designed to carry a significant structural and/or ballast weight. In most cases, operating draft is moderate, typically 0.5-1.5 m, though high capacity feed storage/distribution barges may be designed with a deep hopper profile, allowing feed to be distributed efficiently from the base. Further details are given in the following sections.

Vessel types and specifications

A number of vessel types in common use in offshore aquaculture in various locations are described in the following sections to illustrate typical specifications and features. These are based on specific models, but similar features may be found in a number of comparable design types. Their inclusion in this description does not imply endorsement or approval of particular models; this will depend on decisions for the suitability for the intended purpose.

Single-hulled vessels

Light plastic service vessel – The Thunder Skiff

This flat-bottomed boat (Fig. 1), designed specifically for the Canadian aquaculture industry, is constructed with a floor and tubular hull of high density polythene (HDPE). It has a high degree of versatility, being used for transport of personnel or feed, as a base for automatic feeding, for net changing, and as a basic work platform.

The main HDPE hull/flotation tube is 20" diameter (51 cm) and can be foam filled. The side wall pieces are 12' long x 0.75" thick (3.65 m x 19 mm), topped with a 2" (5 cm) rubberized protection strip which eases the handling of feed bags, nets and other materials. To increase its rigidity, the base is reinforced with tubing of 5" (13 cm) external diameter, which also protects the vessel in rough weather.

Its displacement varies from 3 to 4 tons for the 21 ft (6.4 m) and 28 ft (8.5 m) models, and the vessel offers a good combination of low maintenance cost, high manoeuvrability and excellent stability. The standard design of both models also incorporates compartments for placing a battery and fuel, to assist when the craft is motorized.

Tasmanian aquaculture service vessels

All the service vessels employed in marine aquaculture farms in Tasmania are classified as commercial vessels by the local authorities (Tasmanian Marine and Safety) and have to comply with the "Uniform Shipping Laws Code of Australia". The stability requirements of these laws impose important restrictions on freeboard, which must not be reduced by more than 50%, and the list (lateral angle) when loaded must not exceed 5°.

Light plastic service vessel – The Thunder Skiff

11.9 m reach, developed to maximize crane capacity in a vessel of small dimensions (Fig. 2). Two vessels of this design operate in the S of Tasmania, used for changing nets, placing and servicing mooring systems and occasionally moving cages. The design is based on a flat-bottomed "sampan" configuration, with a high displacement volume and a high forward profile, for maximum crane loading (>4.5 t) while maintaining the required freeboard. Twin inboard engines and propellors permit a high degree of manoeuvrability for work on cage and anchors. The rear wheelhouse is offset for deck access, balancing the position and allows a clear forward working area. The sampan form offers relatively low drag and high speeds for its length, up to 9 knots.

Fig. 1. Light plastic service vessel – The Thunder Skiff (Maritime Aqua Service Ltd.).

Fig. 2. Crane Vessel (Murray Isles).

The use of a 5 mm plate steel hull and deck creates a heavy displacement allowing the crane handling weight to be increased. The design volume allows up to 2.67 t to be carried per m^2 of deck, which allows capacity to be estimated by vessel length. Most of the Tasmanian farms use auxiliary water or air pressure equipment for distributing feed to cages. Most recent designs are of 7 m and can carry up to 3 t of food. Vessels dedicated specifically to feeding are constructed of aluminium and frequently experience problems of structural damage. To understand this, it is notable to realize that these vessels typically operate around 3000 hours annually, double that of commercial vessels, under conditions which commonly risk collisions with cages and other vessels.

As farms and cages are increasing in size, it becomes necessary in turn to increase feed carrying capacity, developing different designs for feeding vessels. One such has been developed in late 1997, transporting up to 7 tons of feed with only 10.14 m vessel length. To ensure adequate stability, 50% of its total displacement is represented by the feed load, and the storage is divided with bulkheads, in the centre of the vessel, with a centre of gravity as low as possible. This storage area is reinforced with a 4 m brace.

The need for a high degree of manoeuvrability around the cages and moorings has favoured a direct propulsion system, with either outboard or inboard/outboard engines in spite of their relatively high maintenance costs. The most recent design has installed a "Jet unit" which gives a good propulsive thrust for this quite heavily loaded vessel, and also permits the feed storage section to be lowered without increasing the draft below the drive shaft.

Shellfish culture service vessels

The vessels which are used for servicing the Galician shellfish (mussel culture) systems have developed their own specific features. Constructed in the local yards with timber hulls around 20 m length and with a fore or aft wheelhouse, providing ample working space for carrying out the complete range of work needed for shellfish culture. Figure 3 shows one of the typical present day designs.

Fig. 3. A typical shellfish culture service vessel from Galicia, Spain (Nodosa).

Equipped with powerful hydraulic cranes, and also provided with a shelter which allows the ropes to be hoisted under cover, avoiding handling losses; the rope can also be stowed in the bottom of this area. The large size of these vessels is dictated by the demands for capacity involved in the transport of the harvested shellfish to the landing place, as well as providing sufficient space for the entire harvest to be worked on.

Auxiliary craft

A number of Scottish and Norwegian manufacturers offer a mid-sized range of very versatile auxiliary flat-bottomed square stern steel craft, covering a wide spectrum of needs in mariculture installations. The smaller boats, all equipped with single or twin outboard motors, are between 4.9 and 6.4 m length, 2.3 and 2.5 m beam and 0.75-0.84 m draft, with a capacity between 500-1000 kg. These are usually open boats, with at most a simple deck shelter. Larger craft have inboard, or inboard/outboard diesel engines of 75-200 hp, typically of 7.3 m length, 2.8 m beam, draft from 1 to

1.15 m and cargo weight of 1500 kg or more. These are equipped with forward or aft wheelhouses, and may be decked. The largest are usually decked, typically steel hulled, 11.95-15 m in length, beam between 5 and 6 m and carrying capacity between 8-20 tons. Larger craft are commonly equipped with hydraulic cranes. Figures 4 and 5 show two such models, the first with a forward wheelhouse, with a fish pump on deck, the second with an aft wheelhouse and a forward mounted hydraulic crane.

Fig. 4. Smaller Auxiliary Craft (Malakoff and Moore).

Fig. 5. Larger Auxiliary Craft (Malakoff and Moore).

Catamarans

The use of a catamaran format allows a high degree of versatility with good manoeuvrability, providing a means to service a marine cage installation or suspended culture systems for mussels, oysters or clams. The double hull shape also offers important advantages in reduced drag and higher speeds relative to waterline length. Typical functions include transport of live fish, change of nets, feed transport, and the means to harvest fish from the stern. These catamarans may be designed in conjunction with aquaculture companies in the Atlantic and Mediterranean, and offer a high degree of stability under load, permitting range of work to be carried out in very secure conditions. Some models are described below.

General purpose cargo boats

This is designed specially for aquaculture with an inboard stern well, constructed from marine grade aluminium (Fig. 6) The shape of each hull is "hydroconic", asymmetric, with specially designed ribs, planning contours and totally developed curves. The double hulls are symmetrical along the directional line and are divided transversally into three tank spaces. The fore and aft tanks of each hull provide access, with hatch covers for bad weather. To improve stability and reduce roll and pitch two stabilizers are situated in the base of each hull.

Fig. 6. Cargo Catamaran (Corelsa).

Principal characteristics:

Hull	Engine	Capacity
Length .... 6.80 m Beam .... 2.50 m Draft .... 0.90 m Ballasted draft .... 1.15 m	Outboard water cooled 3 cylinder diesel with vertical shaft, 4 speeds, 1.1 litter, 36 hp at 4500 rpm; direct saltwater cooling intake, rubber lined pump. Electric starter and backup starting cord. 12v x 10a alternator	Standard design loading of 1000 kg, projected to be able to carry 2000 kg in practice

Catamaran service boats

This boat (Fig. 7) is constructed with marine aluminium panels with timber lateral protection elements. Principal characteristics, equipment and other features are as follows:

Principal characteristics	Equipment	Other features
Total length............ 12.80 m Total beam, inc. lateral protection...... 4.95 m Draft .... 1.25 m	Two diesel inboard/outboard engines, 87-100 hp at 2200 rpm Two x 400 l fuel tanks Crane, with winch. Auxiliary power winch (1.5 t pull) at bow Pump for deck cleaning Two x 12v batteries for starting and for navigation lights	Forward wheelhouse, with all-round windows for good visibility

The overall layout of another more completely equipped type of catamaran, is shown in Fig. 8. Outline specifications include: Material: galvanized steel; length: 7.9 to 13.0 m; beam: 2.9 to 6 m; covered payload 5 to 20 t.

Fig. 7. Service Catamaran (Corelsa).

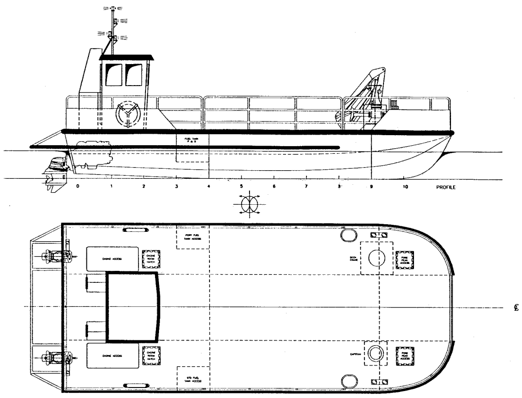

Fig. 8. Service Catamaran (Malakoff and Moore).

Advanced designs

Norwegian and British yards have designed various series of large and specialized vessels which are sized to carry out service and maintenance requirements for large aquaculture installations, and also to transport live fish. As examples, information is given of the general characteristics and overall layout details of three vessels designed and constructed by different yards.

Figure 9 shows the overall layout of the "Ronja Christopher" Details are given subsequently.

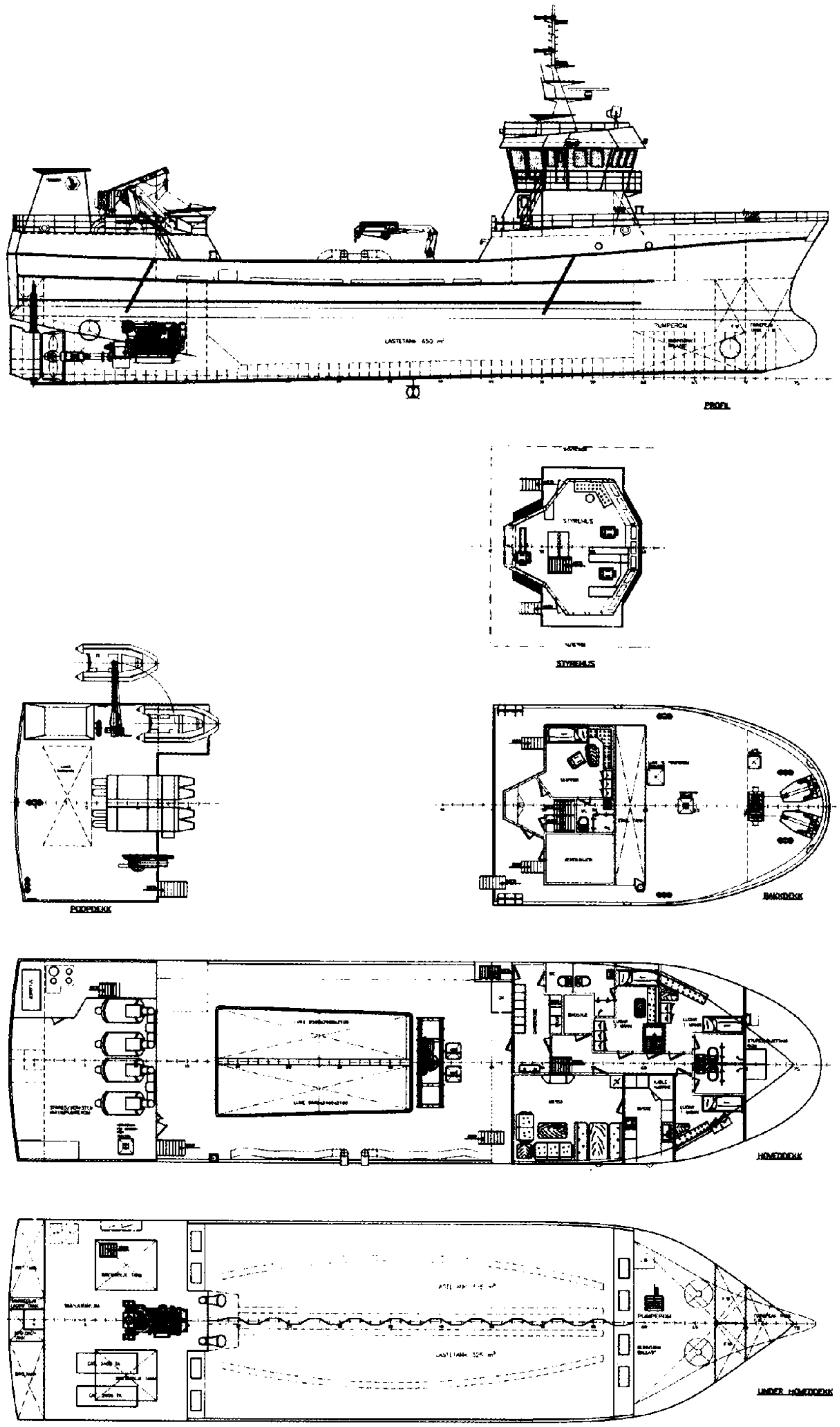

Fig. 9. Large and Specialized Vessel (Design/building yard: Aas Mek. Verksted A/S, Norway).

Length	40.35 m	Auxiliary generators	2 x 300 KVA
Beam	10.00 m	Speed	12 knots
Draft	4.6 m	Capacity	650 m^3 (100 t live fish)
Registered tonnage	499	Equipment	Water circulation – 5000 m^3/h
TRB Motor	1020 hp	Oxygenation	2 x 80,000 mg/h

Another of the examples given was designed by a marine engineering and naval architecture consulting company which developed a new generation of live fish transport vessels using refrigerated sea water (RSW) to the required temperature levels. Key features of this 40 m x 10 m vessel centre on the propulsion system, which is designed to minimize noise and vibration, the cause of significant stress to transported fish, and the specific design of the live fish holds and their water circulation. Ancillary equipment includes the RSW system to reduce activity and metabolism levels and minimize stress to the fish, and an ozone system for reducing or eliminating bacterial loads. Figure 10 shows a side elevation for the design. Note also the directional propellor system and the front-mounted propellor (bow thruster), for extra manoeuvrability, the large fish well and loading crane, and the ancillary rear deck crane for deck cargo handling.

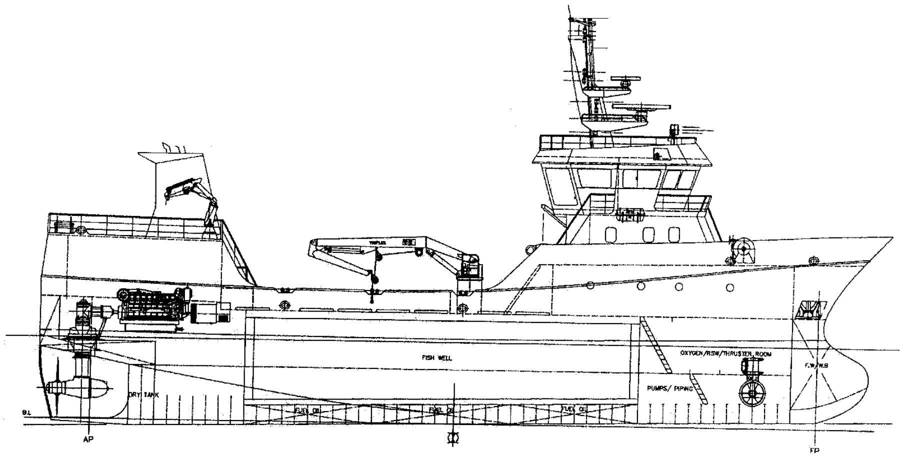

Fig. 10. Live – Fish Boat (Skipsteknisk).

Figure 11 shows the third example, the "Crier", which has the following characteristics.

Fig. 11. Scottish Salmon Farming Workboat ("Crear", David Harris Shipping Lmt.).

Main engine power..855 BHP
Gross weight ....423 t
Auxiliary generators..2 x 125 kW
Crane...21 t
Water volume (live fish) ....330 m^3
Speed..9 knots
Classification ....Lloyds

Feeding platforms

These units are like floating silos, taking the form of semisubmergible vessels, with a conical base, capable of holding between 50-400 t of food, delivering 20-80 t daily. The major part of these silos is normally below the water level, where it is kept dry and at a far lower or even temperature. During the summer months in the Mediterranean, the food will be at the same temperature as the seawater, and thereby the vessel acts as a form of cold store. Figure 12 shows one of these designs.

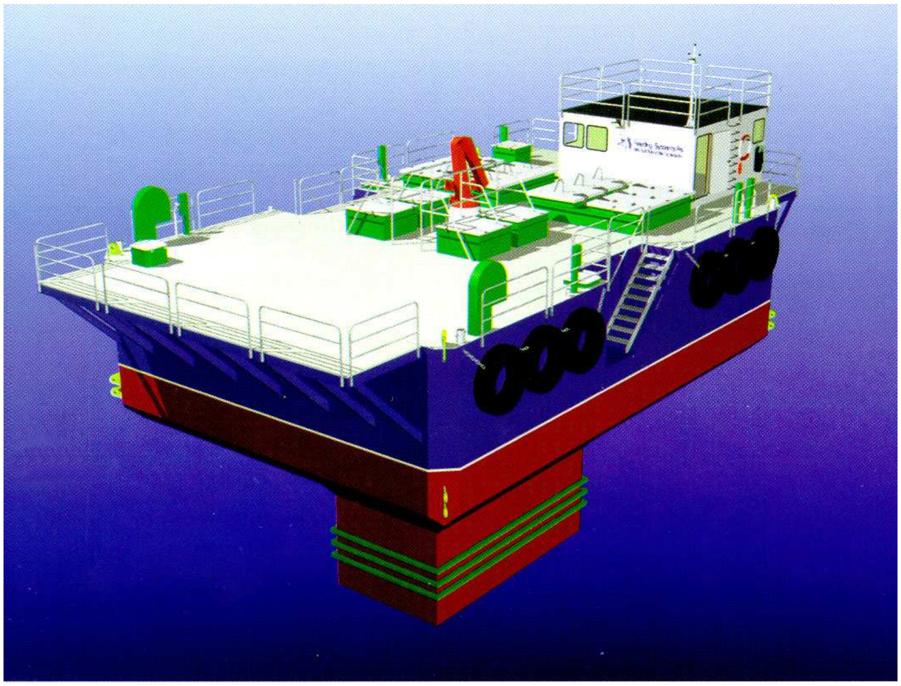

Fig. 12. Cone Barge (Feeding Systems A/S).

A great advantage of these floating silos is that they minimize the need to handle bags of food, as the feed can be loaded and distributed directly, using blowers and automatic feeding systems. In traditional systems, feed may be handled up to three times, which represents a major labour cost. These specialized feed units are normally equipped with centralized feed delivery systems and would normally include silos, cranes, lifting gantries, diesel generators, fuel tanks, containers or housings to store the equipment, and in some cases, accommodation or other facilities for the crew. The units may therefore have the potential to become virtually self-sufficient.

Total automation though not carried out so far, would include all the aspects of processing feeds; milling and compounding, storage, and automatic distribution.

These vessels are also highly stable in poor sea conditions. Installations in the W coast of Canada have easily withstood storms with 5 m waves, which have been excessive for traditional units. The most important advantages with respect to traditional units can be summarized as: (i) very high storage capacity, which implies a significant reduction in feed replacements; (ii) no handling of feed since deliveries are automatic; (iii) completely automatic systems up to 80 t per day; (iv) eliminates all problems of on-site feed storage; and (v) can result in production cost reductions of up to 50% (excluding differences in capital cost overheads).

The associated "Windows" – based software allows the operator to control quantities and delivery times with great precision, as well with automatic as with manual feeding. It is also possible to install video systems to improve the precision of judging the feeding response and controlling feed delivery under automatic conditions. This "cone barge" design has now been installed in more than 15 farms in Norway, Scotland, Chile and in British Columbia in Canada.

Another feeding vessel design is in a hexagonal form, minimizing resistance to wave forces and ensuring good stability in extreme sea conditions. Figure 13 shows a drawing of such a system, the Akva "Hexagon", which is available in models of silo capacity from 120 to 322 m^3. All the incorporated equipment (feeding system, diesel generator, feed store) is at the same level below the deck, well protected from wind and waves, except for the feeding control and delivery system, which is above deck to facilitate access for maintenance and to allow control signals to be sent between the shore base and feeder unit, and between the unit and the cages. All the personnel space is below deck and at or below sea level, where movement is less significant.

Fig. 13. "Hexagon" Floating Feed Barge (AKVA).

The characteristics of the platform are as follows:

Length	10.4 m	Displacement	110 t
Breadth/beam	12.0 m	Food store capacity	110 m^3/6 silos
Draft	8.4 m		162 m^3/3 silos
Freeboard when loaded	0.8-2.2 m		216 m^3/4 silos
			323 m^3/6 silos

Figure 14 shows the operation of this platform with a feed control system. This can be linked with a system of sensors which can continuously monitor and optimize the consumption of food by the fish in the cage. The sensor monitors the passage of the food across the scanning area, which transmits data to the system software. The food is controlled automatically to pre-set limits and is further controlled if excess uneaten food is detected below the normal feeding zone of the fish. With such a system it is claimed that the Food Conversion Ratio (FCR) can be considerably reduced – for salmon, towards levels as low as 0.8. For a farm of 600 t annual production, with a feed price of £0.64 per kg, this would represent a typical annual cost reduction of £137,000. To this gain would be added the reduction in wasted food and the consequent reduction in environmental impact.

The whole system is "wire-less" and is operated using a Doppler sensor, a signal receiver and a food distribution impeller. The Doppler sensor can monitor the passage of food particles with great precision over an area of 20-28 m^2. An underwater camera, installed together with the sensor unit, serves to monitor the behaviour of the fish. Each cage contains such a combined sensor/camera unit. The impeller, which controls the delivery of feed, is installed at the end of the food delivery pipe (see inset diagram) and is set above the level of the cage. The energy for the doppler sensor is generated by the air flow in the system from the feeding unit.

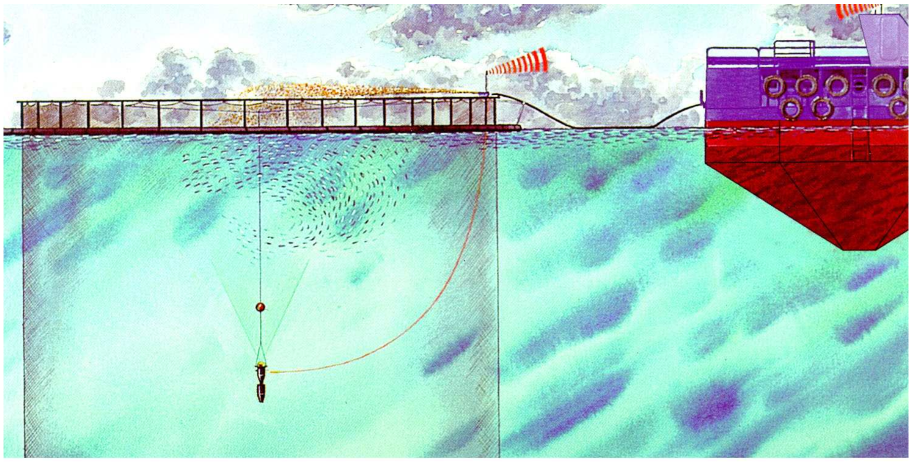

Fig. 14. "Hexagon" Barge with Feed Control System (AKVA).

Conclusions

A number of countries have a long tradition of constructing and operating fishing and service vessels for a number of purposes, and this has served the initial stages of aquaculture development very effectively, with smaller scale operations in fish and shellfish culture in inshore waters. The development of offshore oil technology, and the service systems associated with its operations, together with recent advances in telecommunications and control systems are now offering increasing opportunities for addressing the challenges of offshore aquaculture, where operations will be greatly influenced by difficult sea conditions, by the need for reliable automated systems, and by the need for overall safety and security. Key elements in offshore aquaculture are the safe and secure installation of facilities, the supply of live fish for stocking, delivery and efficient distribution of sizeable quantities of feed, effective monitoring and management response to system and stock integrity, and timely and efficient harvesting of good quality product. New vessels and support systems are still being developed, and are already showing the potential to make significant changes to the opportunities for larger scale offshore aquaculture. Though technological inputs and costs may be high, the gains in efficiency and operating security should justify their application. Such service systems are becoming and increasingly important element in the design and development of projects, and need to be carefully considered, along with other key system and operational features.

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