Composting Seafood Waste

July 2004

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ADAS Environment

PROJECT PART-FINANCED BY
THE EUROPEAN UNION
THROUGH THE FINANCIAL
INSTRUMENTS FOR FISHERIES
GUIDANCE

Working with the seafood industry to satisfy consumers, raise standards, improve efficiency and secure a sustainable future.

The Sea Fish Industry Authority (Seafish) was established by the Government in 1981 and is a Non Departmental Public Body (NDPB).

Seafish activities are directed at the entire UK seafood industry including the catching, processing, retailing and catering sectors.

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FINAL SUMMARY REPORT

Seafood Waste Treatment.

COMPOSTING SEAFOOD WASTE

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EXECUTIVE SUMMARY

Increased global awareness of environmental issues has stimulated much attention to waste minimisation and waste management at UK and EU level. Governments have resorted to regulation and economic instruments such as The Landfill Tax in order to dis-incentivise the landfilling of waste and especially biodegradable waste such as from the food industry.

Meanwhile, bio-security issues have been brought to the fore by animal disease outbreaks (Foot and Mouth disease) and some limited cases or fears of human food contamination (Ecoli 0157, Listeria, Salmonellae). This focus on bio-security has contributed to the regulations regarding animal by-products that are now formalised in The Animal By-Product Regulations 2003 (ABPR2003).

The ABPR2003 brings significant new controls to the food industry and includes sea-food waste. One part outlaws the direct landfilling of sea-food waste and another requires that various minimum standards of treatment are required if the food waste is to be recovered as fertiliser for use on land.

Sea food waste and residues during food processing are in the main, regulated as Category 3 animal by-products and as such, may be utilised in the preparation of fertiliser or soil conditioning material subject to being composted or anaerobically digested in compliance with strict conditions.

This report focuses on high temperature composting and follows a range of mixes of sea-food waste with household 'green waste' (i.e. grass clippings, hedge trimmings and garden vegetable residues), through the composting process as replicated treatments and concludes with bioassay and plant growing trials on the resultant composted material.

The principal sea-food waste types were: pelagic/oily fish (mackerel), demersal fish (mixed white-fish species)and shell-fish (comprising crab, mussels, *Nephrops* and whelks). These were studied as four treatments; one for each of the seafood types mentioned and one for a complete mix of all of the seafood types. These seafood types were admixed to green waste in the wet weight ratio of approximately 1 part fish to 3 parts green waste. In each case there were three replicates and each replicate comprised approximately 4 tonnes of material.

The trial configuration was based on 6 composting chambers, each of 2.4 x 2.4 x 2.4 metres of insulated timber construction, plastic lined and with integral ventilation recirculation and control systems. Air exhausted from the chambers was ducted to a wet scrubber tank and biofilter. The target retention time was 6 weeks. Observations were made daily and samples taken at intervals.

The trial results revealed that all the types of seafood had very low Carbon to Nitrogen (C:N) ratios in the range 4:1 to 7:1. The mixture strength with green waste was deliberately retained as 'strong in favour of the fish' to represent a commercial approach. Feedstock starting quality was generally C:N ratio 8:1 – 22:1 and dry matter 25 – 30%. Contaminants and other analytical measures were within the range of expectancy and all were within nationally recognised standards except for moderately raised levels of some elements in some types of shellfish.

In each case the temperature of the feedstock rose quickly to around 70 degrees C and remained at that temperature for several days. During this time, evaluations of various pathogens revealed that Ecoli, Salmonellae, Clostridium perfringens and Enterobacteriaceae could be controlled within a period of less than 3 days using this regime.

The resultant compost material was assessed in several ways: analytically in bioassay and in growing trials. Given the mix of materials, the composted product was shown to be soil-like as defined by the BS3882 Topsoil standard although pH and stone (shell) content were notable issues.

In terms of contamination, the materials were within the thresholds for the Publicly Available Standard for composted green-waste - PAS100:2002, (except for stone (shell) content).

The bioassays revealed that the material was not suitable as a basic growing media on account of electrical conductivity and some phytotoxic issues where the oils particularly in the oily fish promoted mould growth in the growing media. It is generally accepted that most types of composted livestock waste or vegetation waste materials are precluded from being used as growing media for reasons of electrical conductivity – i.e. the 'salts' content of the material inhibits moisture release to the tender growing plants thus causing droughting and wilting.

In the growing trials, where the material is only added to the soil as a dressing to provide between 0 and 400 kg/ha of total nitrogen within the material, then it was shown that tomato and barley plants had improved germination and establishment compared to the control and that the growth and yields of plants were generally better than the control. Notable exceptions were with the mackerel based composted material where the higher additions (400kg/ha as total N) of material generated mould growth on the soil surface and some loss in vigour of the plants. The moulds were assessed as being predominantly penicillin types.

The project concluded with technical and financial consideration of biological treatment facilities that are available to the market-place for the treatment of sea-food waste. Some facilities utilising similar animal by-products (such as the Bioganix Bio-drum) are following a process of minimal green-waste admixing; and countering the exhaust of ammoniacal and other emissions by utilising sophisticated gas-clean-up and liquid fertiliser recovery techniques. Anaerobic digestion is proven for some animal by-product materials, but less so for sea-food waste. Given some measure of carbon admixture, the wet fish material lends itself to biogas and fertiliser recovery using anaerobic digestion and some techniques of flushed bio-reactor may even be capable of utilising the shell-fish waste.

However, it is the contemporary 'In-Vessel' composting type operation that appears the most suitable for this material. Such techniques will rely on the admixture of green-waste, or other such carbonaceous bulking agents, of which there is an almost ubiquitous supply.

With the tight regulation and contracting arrangements within the waste management industry, and for reasons of food factory policy in regards to waste, it may be concluded that that the recovery, composting and recycling of sea-food waste is something that is better serviced by the waste management industry rather than the food industry. The waste management industry will be better placed to reduce costs and increase the benefits due to the economies of scale.

In this regard, it is concluded that this project has provided the reassurance that sea-food based composted materials can provide useful soil-conditioning and nutrient adding properties for agricultural land including reclamation and forestry land.

The Bioganix process of minimised carbon addition is worthy of closer investigation as it may be of greater merit for areas where green-waste or other materials are not available or are to be avoided.

In conclusion it is recommended that the next phase of development work should involve both the sea-food and waste management industry, in close liaison with local authorities and regional agencies for food industry regeneration and sustainability. More specifically, some opportunities are emerging for further work at sites such as the south-west of Scotland (Scottish Executive project using Biogas technologies), Lancashire (development of centralised facilities for biological treatment) and Northern Ireland.

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SECTION 1.0 INTRODUCTION & BACKGROUND INFORMATION

1.1 LEGISLATIVE BACKGROUND

Environmental and legislative pressures have generated the need to identify environmentally friendly and sustainable techniques for the recycling or disposal of sea-food waste.

Under the Environment Protection Act 1990, various regulations were established for the handling and treatment of 'controlled waste'. Waste includes anything that is discarded, or is intended to be discarded and isn't necessarily restricted to things that have no value. Thus in the same way that Landfill Operators have to comply with very strict licensing or permit conditions, then so does anyone who keeps treats or disposes of waste, regardless of whether the intent is to recover and recycle the material with some form of added value.

The controls and regulations that apply to sea-food waste include The Waste Management Licensing Regulations 1994, The Town and Country Planning Act and The Animal By-Product Regulations 2003 (ABPR2003).

The ABPR2003 creates new challenges for the seafood industry, is complex and is double edged in that in one part it outlaws the direct landfilling of sea-food waste and in another requires that various minimum standards of treatment are required if the sea-food waste is to be recovered for use as a fertiliser type material on land or is simply intended for disposal in landfill.

Within the Animal By-Product Regulations there are 3 main categories of material; 1 relating primarily to diseased animals, 2 relating to fallen stock or inedible components and 3 as being material that may be used for food (for humans) but for various commercial reasons is discarded.

The Regulation provides a definition as follows:

Category 3 material

Category 3 material shall comprise animal by-products to include the following, or any material containing such by-products:

- fish or other sea animals, except sea mammals, caught in the open sea for the purposes of fishmeal production;
- fresh by-products from fish from plants manufacturing fish products for human consumption;
- shells, hatchery by-products and cracked egg by-products originating from animals which did not show clinical signs of any disease communicable through that product to humans or animals

- In relation to composting, the Regulation requires thatCategory 3 material shall be collected, transported and identified without undue delay in accordance with [*various specifications*] and shall betransformed in a biogas plant or in a composting plant approved in accordance with Article 15;

Composting or Anaerobic Digestion (AD)

Category 3 material used as raw material in a composting (Or Biogas - AD) plant must be submitted to the following minimum requirements:
(a) maximum particle size before entering the composting reactor: 12 mm,
(b) minimum temperature in all material in the reactor: 70 °C; and
(c) minimum time in the reactor at 70 °C (all material): 60 minutes.

Where the animal by-products are residual from the catering industry or where the waste materials are converted to a form where they are ready to eat without further cooking and are therefore 'former food-stuffs' then other criteria may apply.

Alternatives

The alternative to utilising this route to recycling of the waste, would be to render the material and dispose of the residues, or to identify an alternative 'technical' treatment process and develop this to meet the standards required.

Opportunities Once Composted/Digested

Once converted by composting or digestion, and subject to various quality criteria, the waste material may be utilised for various purposes in agriculture, or other instances of food or non-food crop production e.g. land reclamation, biomass production or forestry.

1.2 SEA-FOOD WASTE ARISINGS

Sea-food waste quantities types and composition are very well documented in; The Sea-Fish Industry Authority Research document 'Fish Waste Production in the United Kingdom' 2001,.

The data provides an estimate of the overall quantity of sea-food waste as shown at Table 1. below.

Table 1: Estimates of Overall quantity of sea-fish waste landed in the UK

Region	Product Processed %	Estimate of Waste Produced (tonnes)
Humberside	44 %	132,456
Grampian	29 %	87,302
Northern England	6 %	18,062
South West England	5 %	15,052
South, Midlands and Wales	5 %	15,052
Highlands and Islands	4 %	12,041
Other Scotland	4 %	12,041
Northern Ireland	3 %	9,031
TOTAL	100 %	301,037

1.3 UK - WASTE MANAGEMENT

Waste management is a growth industry in the UK and initiatives for recovery and recycling of waste are currently being undertaken in accordance with the UK Government's Strategy to meet onerous waste recycling and EU Landfill Directive targets.

About 28.8 million tonnes of municipal waste were collected in England in 2001/02; most waste currently ends up in landfill sites, but around 35% of industrial and commercial waste and 12% of household waste is recycled or composted. Green waste composting, currently contributes 0.9 million tonnes (i.e.30 per cent) towards the 3.2 million tonnes of household waste recycled. Such is the potential for biodegradable waste to be recycled by biological processing, i.e. over a third of household waste is green/biodegradable waste, that Local Authorities are benefiting from multiple sources of funding either directly or indirectly from UK Government. Composting type schemes for the recovery and recycling of green and biodegradable waste will have the capacity to co-

compost other industry residues such as sea-food by-products and consequently some synergy values are worthy of consideration in the search for solutions to the sea–fish waste issues.

1.4 SEA-FOOD INDUSTRY WASTE COMPOSTING RESEARCH

The review into research and trials previously undertaken revealed that much effort had been placed on passively ventilated windrow or small ‘in-bin’ systems but that very little work has been done with controlled composting type techniques.

The majority of references relate to the northern fishing countries including North America, Canada, Alaska, and Scandinavian Countries. Besides from key fishing areas, these are also rich in timber production and processing and this is reflected in the approach where the use of timber processing residues (sawdust and woodchip) are the main bulking and amendment material.

Further south, the more freely available green-waste and ‘yard-waste’ type materials are mentioned together with various trials using horse stable manure, cane bagasse and other such industry residues.

The rationale for the research is generally for environmental protection with attention to odour and then water pollution. There are many references that refer to the processing of these wastes for agricultural or even horticultural use afterwards. More recent research cites new or impending legislative reasons for the need to identify sustainable and environmentally satisfactory techniques.

Given the influence of the northern areas, the predominant technique is to use bulk mixing of the fish waste with sawdust or woodchip and to form this into windrows estimated as ranging 2 - 4m wide, 2 - 3m high and 20 - 50m length. One system used a layered windrow comprising a base layer of 150 – 300mm, then the feedstock for composting to form an arched windrow over the base layer

The research focuses on the input material moisture content and Carbon to Nitrogen (C:N) ratios and generally will be seen to utilise copious quantities of the freely available wood residues and therefore report the work in terms of reduced odour, and usable material after many months of composting. In some instances the windrows are mixed and turned through the period, but this is variable.

Much of the research concludes with some assessment of end product qualities in relation to agricultural crop use. Several results report the effect of using various types of wood residue, and form the conclusion that the composted material out-performed the control by 50% or more in terms of crop yield or weight gain.

The ‘in-bin’ systems, which are designed for the purpose of keeping the lake and riverside fishing areas clean, are formed of timber construction and may comprise three or more 1cu.m frames with passive ventilation incorporated into the design using false floors or side ventilation grills. It is useful to note that in some trials the temperatures achieved were generally in the mid 30^{o} Celsius with some rising up towards 45^{o} – 50^{o} but rarely higher. Again, odour control and pollution avoidance is the main aim. Some cite pathogen control, but this has generally not been the focus.

More recent research in Ireland (The Bord Iascaigh Mhara (BIM) – Irish Sea fisheries Board - March 2002) using the ‘Gore composting system’ takes the types of process described above, to a more controlled stage by using actively ventilated windrows individually covered with ‘Gortex’ textile sheeting for rainwater protection and air exhaust. Mixed waste (shellfish – crab/mussel and salmon processing waste) was placed in a windrow of 20m x 6m x 3m , laid on a bed of sawdust and overlying a single central aeration duct. Some material was taken in late March for supplementing a wormery trial. The trial ran to May 2002 when the air blower was isolated and the compost allowed to stabilise and mature naturally. The trials work is well documented and provides much data regarding analyses, temperature regime and material stability.

Later trials were undertaken using a small scale Reactor type composting vessel supplied by Alternative Waste Solutions (AWS) of Tyne and Wear. A feedstock comprising Mussels and Winkles was mixed with MDF dust and a separate trial was undertaken with Salmon waste.

BIM concluded that composting of organic seafood processing waste can be a viable option for waste disposal and that different options are available depending upon the size of the business and amount of sea-food waste generated.

1.5 SEA-FISH INDUSTRY AUTHORITY RESEARCH OBJECTIVES

The seafood composting project has been devised with the aim of determining the safety & practicality of seafood by-product composting, whilst also identifying the potential marketability of the compost itself. This then provides a basis for advising industry. Specific objectives are:

- To determine the effectiveness of biological treatment in the proper stabilisation and pathogen kill for specific types of fish waste.
- To evaluate different feedstocks (each mixed with typical green waste) including demersal fish only, pelagic fish only, shellfish only (crabs, *Nephrops*, mussels and whelks) and combined fish and shellfish.
- To determine the safety & marketability of all the resultant material for potential use in end markets.
- To provide guidance for the UK seafood industry.

This report summarises the main findings of the project including trials methodology and results. Further detailed information can be found in the full ADAS report, available from Seafish.

SECTION 2.0 COMPOSTING TRIALS

2.1 COMPOSTING TRIALS APPROACH

The sea-food-waste composting trials were designed to enable comparisons between different seafood -waste types admixed with shredded green-waste materials comprising grass clippings, leaves and other waste shrub/vegetation/plant material.

Facilities were established where 6 enclosed composting chambers could be utilised concurrently to compost batches of approximately 4 – 5 tonnes of mixed sea-food and green waste material in each chamber. The 6 chambers accommodated two sea-food/green waste trials each comprising 3 replicates at any one time.

Following a phase of preliminary trials and general procedural assessment, four sea-food and green waste mixtures were composted. These included whitefish (demersal) waste only, Oily (pelagic) fish only, shellfish only and mixed fish/shellfish. Each composting trial was operated for approximately 6 weeks and was followed by a growing trial using glasshouse grown pot-plants (tomato and barley) to assess the efficacy of the finished compost. The ‘growing trials’ were run as a multiple trial after the completion of all of the phases of composting.

A series of chemical, physical and biological analyses were undertaken to assess the safety and quality of the material during and after each batch of composting. A statistically relevant sampling plan was prepared to elicit representative, credible results based on composite samples of the seafood/ green-waste materials prior to, during and after completion of the composting process.

The composting and growing trials were scheduled for September 2003 to March 2004. A separate vermiculture trial of the sea-food waste compost was scheduled to be conducted by The Worm Research Centre at Goole during March 2004.

2.2 COMPOSTING TRIALS FACILITY

Trials Facility

On the basis of the research and objectives, it was necessary to define a facility that was typical of industry current practice and yet which provided the degree of statistical representation required. This precluded various prototype self contained/auxiliary heated in vessel ‘composting’ systems.

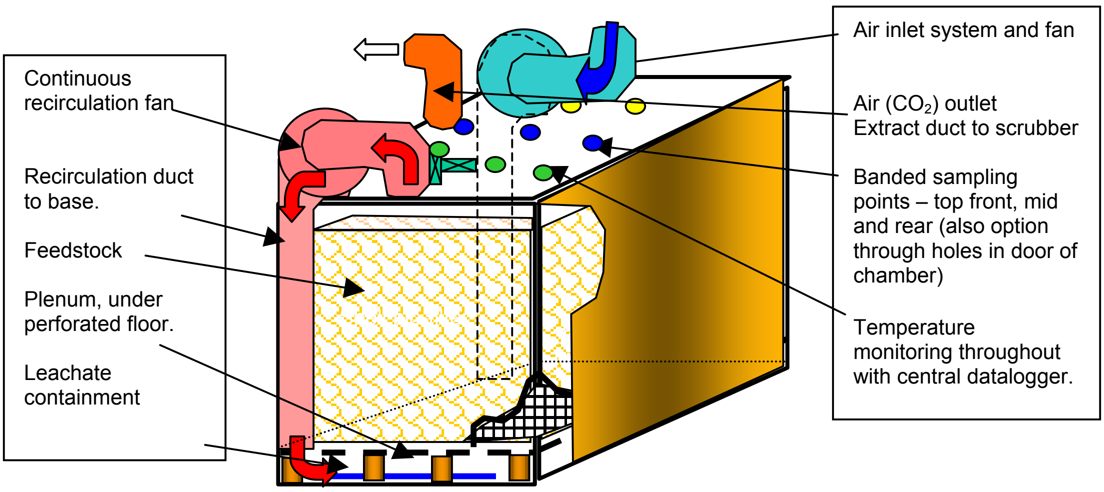
The largest industry examples for composting of organic waste under controlled conditions were to be found in the composting of feedstocks for the mushroom industry. A reference site at Hensby Ltd, St. Ives Huntingdon was visited and used as an industry scale model.

A pilot scale, research facility, based on this model was established at ‘Extra Farm’ Boxworth, Cambridge. The facility was planned to operate on a Waste Management Licence Exemption, and short term approval in relation to Animal By-Products was sought from the State Veterinary Service.

The site was selected due to its remote position, ease of access for vehicles and the site infrastructure and facilities. The facility comprised a fully enclosed in-vessel composting system with a set of six identical chambers each capable of holding approximately 4-6 tonnes of material.

Each chamber was of 2.4m x 2.4m x 2.4m dimensions and was built of timber beams and sheets with integral insulation material to provide walls and roof panels of 150mm thickness. The roof panels and fronts were removable to enable entry for filling and emptying. At the base of each chamber was an air plenum, comprising a suspended floor with a slatted cover. Vertical air ducts together with a ventilation fan arrangement provided either recirculated air or ambient air to the plenum. The plenum facilitated air distribution to the material within the chamber. The fans were controlled by a system of simple time switches and thermostatic controls. Any displaced air from the system was exhausted to a water wash (scrubber) and wood/bark biofilter. Multiple temperature probes connected to a data logger recorded the process temperatures at set intervals.

Figure 1 - Illustration of a composting chamber



<u>Composter sampling</u>

Using an auger sampling tool, the sub-samples of material were extracted from the composter by using a series of sampling access holes cut into the lids and doors of the chambers. Sub-samples were taken at two levels and from the front, middle and rear of the chamber. The sampling tool was disinfected and washed prior to each sampling.

2.3 COMPOSTING TRIALS OPERATION

The main composting trials were preceded by a series of preliminary trials designed to provide information and commissioning of the trials regime and procedures to be employed. For the 'Main' trials, given the need for 3 replicates for each treatment, the facility accommodated two treatments at any one time. The Pairs of treatments were as follows:

FIRST TRIAL	SECOND TRIAL
Mackerel with green-waste	Shell-fish with green-waste
White Fish with green-waste	All fish mixture with green-waste

The mixes of Fish Waste to Green Waste were characterised by analytical methods of the base ingredients and parameters of Carbon to Nitrogen ratio (C:N ratio), Carbohydrate composition, nitrogen availability, potentially toxic elements (Pte's) and trace elements inclusion. Gross energy and respiration indices were considered also.

The potentially toxic elements included cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn) in metallic form as well as their salts and oxides.

Various other tests and comparison with industry standards were undertaken in order to bench-mark the quality of the resultant composted materials. For Pte's comparisons are made with BSI PAS100:2002, 'Biowaste Directive standards' and the BS3882 Topsoils standards.

2.4 BIO-ASSAYS AND GROWING TRIALS DESIGN

The Growing trials (plant growth trials) were planned to be carried out in order to evaluate the benefit of the material towards plant growth and at the same time to determine any negative effects such as phyto-toxicity. This was planned as a pot scale fully replicated trial within a glasshouse to reduce the affects of climate and seasonality and therefore provide expediency and control. In addition to the pot-plant growing trials, for the main fish-waste mixes, the resultant composted material was to be subjected to a plant bio-assay in order to evaluate any potentially phyto-toxic affects that the materials may exhibit. Susceptible plants (tomatoes) were used in the growing trials and the bioassay, with Barley in the growing trial also. The composted materials were evaluated in replicated trials against control materials.

SECTION 3.0 PREPARATORY COMPOSTING TRIALS

3.1 PREPARATORY COMPOSTING TRIALS

Preparatory trials were undertaken for the purposes of commissioning the facilities and assessing various factors to be used in planning the mixes and operating regimes to be used in the main trials.

To increase the range of parameters being studied, each chamber was temporarily subdivided into two. This enabled a wider selection of C:N ratios treatment temperatures and feedstock mixes to be evaluated.

The initial pre-trial study was initiated on 12^{th} September 2003. Approximately 2.2 tonnes each of demersal fish, pelagic fish and mixed shellfish and 20.5 tonnes of green waste (shredded hedge cuttings, grass, leaves, and other vegetation) were delivered to site during the previous week. These materials were shredded and then mixed into three different ratios, ranging 1:3 to 1:30 parts seafood to green waste.

Temperature monitoring and measurement were undertaken on a daily basis with sampling carried out to a specified schedule. Manual recording, calibration checks and air quality oxygen testing were also undertaken.

An initial review of the data shows that the temperatures within the various chambers very quickly established within the range 45^{o}C to 60^{o}C. Temperatures were generally lower than target due to some electrical and mechanical problems. However the stronger fish mixes, notably 1:3 parts fish to green waste, reached and held high temperatures during the initial period of the trial.

Interim sampling was carried out 2 weeks into composting trial.

Table 2: Comparison of Feedstock Potentially Toxic Element values with PAS100:2002 standards.
All units are expressed as mg/kg of Dry Matter

PAS100	Cod	Haddock	Mackerel	Nephrops	Crab	Whelks	Mussels	Green Waste
Lead 200	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	37.9
Nickel 50	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	11.7
Zinc 400	60	65.2	77.2	17.8	18.3	546	9.13	94.6
Cadmium 1.5	0.11	<0.10	0.36	<0.10	<0.10	4.44	<0.10	0.42
Chromium 100	2.04	2.29	1.3	1.9	1.51	1.74	<0.20	16.3
Copper 200	1.78	2.8	2.68	4.36	4.35	17.5	1.63	21.1
NH4 -N	13400	18600	7950	7890	4530	3190	2560	75
C:N Ratio	2	2	7	4	4	3	3	14

Microbiological sampling of the mixed seafood and green waste was also carried out. Salmonella was not detectable in any of the samples. Ecoli was present in the feedstock and was therefore a useful indicator of sanitisation. Ecoli levels were variable and generally comparable with typical green waste feedstock materials. The higher values in the feedstock mixtures correlated with the higher rates of inclusion rates of green waste with the sea-food waste.

As the trial progressed, the trend toward very high dry matter continued, i.e. the material in the chambers dried out even though visual inspections gave the impression that the compost was still wet.

Visual inspection suggested that the feedstock material was retaining moisture. It was later found that this higher moisture material was confined to a thin layer at the surface.

Over the duration, it was evident that even at lower temperatures, the Ecoli pathogen count became diminished and brought to zero. A final test revealed that the other pathogens Enterobacteriaceae and Clostridium perfringens were also brought to zero by the end of the period.

Preparatory Trial - Conclusions regarding Mixture Formulation

- Seafood waste contains very high nitrogen and phosphate content, much higher than typical agricultural materials, vegetation or livestock manure.
- The high nitrogen causes the C:N ratio to be very low
- The sea-food waste is significantly low in potash thus making it imbalanced as a prospective fertiliser. The green waste compensates for this.
- Sea-food waste materials are either absent of or contain generally very low counts of the pathogen types tested for in composting/animal by-products regulation – i.e. Ecoli, Salmonella, Enterobacteriaceae and Clostridium perfringens.
- Shredded green waste is potentially a very useful bulking agent for co-composting with sea-food waste and provides a useful balance of nutrients and carbon although its quality is subject to seasonal effects and its pathogen content may be elevated and unpredictable.
- It is apparent that some types of shell-fish waste contain elevated levels of Pte’s. However after admixing and co-composting with green waste they are well within industry standards for land use.

Preparatory Trial - Conclusions regarding operational control

- The sea-food mixtures revealed that the higher seafood content feedstocks tended to compact and slump within the composting chamber.
- Sea-food mixture ratios (by fresh weight) should be no stronger in sea-food than 1 part sea-food to 3 parts green waste.
- Maintaining oxygen levels in the range 17 – 21% may entail excessive input/exhaust and lead to significant moisture losses.
- Exhaust air may be readily cleaned and filtered using a water scrubber tower and wood/bark biofilter combination.

Preparatory Trial - Conclusions regarding composted material exit quality

- The composted material quality was variable from the various treatments, but all samples comfortably attained the industry standards for the Pte’s in regard to PAS100.
- The physical quality in all cases was such that a further mechanical treatment would be required prior to the material being utilised; e.g. screening and or grinding/milling.

SECTION 4.0 THE MAIN SEA-FOOD COMPOSTING TRIALS

4.1 MAIN COMPOSTING TRIALS DESIGN

The main composting trials were designed as two pairs of trials each having three replicates. The feedstock materials in each pair were prepared and loaded to the six composting chambers using an alternating chamber pattern.

The first pair were White-fish and Mackerel, both mixed with shredded green waste in the same ratio and the white fish mix loaded to chambers 1, 3 and 5; with the mackerel mix loaded to chambers 2, 4 and 6.

The ratio of fish to green waste was based on a fresh weight basis of approximately 1 part sea fish to 3 parts green waste. This was selected as being the most likely minimum ratio that would work for an in-vessel composting system and was considered as representative of the most cost effective ratio where maximised throughput of fish per unit volume of composter was the commercial aim.

4.2 WHITE FISH AND MACKEREL COMPOSTING TRIALS

4.2.1 Feedstock Analytical Tests

Feedstock materials were sub-sampled and the fish waste was found clear of the main pathogens Ecoli, Clostridium perfringens and Salmonellae. By comparison, the Green Waste contained relatively high levels of each of these with the exception of Salmonellae.

Table 3: Mean Results of Microbiological Tests of 3 Sub-samples of White-fish, Mackerel and Green Waste Feedstock
….cfu/g (except where stated)

5 November 2003	Clostridia perfringens	E Coli	Salmonella sp
Green Waste	3.5×10^3	10^6	Not Detected/25g
White Fish	<10	<10	Not Detected/25g
Mackerel	<10	<10	Not Detected/25g

This information provides a comfort in terms of human handling and treatment of the sea-food; and for the purposes of the trial means that the green waste enabled pathogen tracking through the composting process.

Chemical Analyses of Fish and Green Waste

Table 4: Mean Results of Analytical Tests of 3 Sub-samples of White-fish, Mackerel and Green Waste Feedstock

5 November 2003	**Green Waste**	**White Fish**	**Mackerel**
pH	7.1	7.2	6.8
Oven Dry Matter, g/kg	472	230	416
Total Nitrogen (Kjeldahl),	8	107	57
Total Phosphorus, mg/kg	1553	44500	12700
Total Potassium, mg/kg	5843	11500	4290
Total Ash, %	44	25	7.7
Organic Carbon, %	17	36	54
Total Magnesium, mg/kg	2507	1900	1143
Total Lead, mg/kg	47	<5.00	<5.00
Total Nickel, mg/kg	13	< 1.0	<1.0

Total Zinc, mg/kg	111	59	49
Total Cadmium mg/kg	0.4	0	0.4
Total Chromium, mg/kg	21	2	0
Copper mg/kg	32	2	3
Ammonium~N mg/kg	91	14300	7227
C:N Ratio	20	3	10

The starting pH's were all just below neutral. The dry matters reflected the influence of the 'wetter' (low dry matter) white fish compared to the mackerel but in both treatments the mixes provided ideal starting moisture levels.

Table 5. The composition of the raw feedstock mixes expressed on the dry weight basis.

	pH	Dry Matter %	Nitrogen g/kg	Phosphorus mg/kg	Potassium mg/kg	Ash % m/m	Carbon % m/m	C:N Ratio
Chamber 1 Whitefish	6.8	36.0	27.9	3793	7817	46	27	10:1
Chamber 3 Whitefish	6.7	35.7	34.1	4527	8137	43	24	7:1
Chamber 5 Whitefish	6.8	37.0	28.9	4533	7753	42	23	8:1
Mean Whitefish	**6.8**	**36.2**	**30.3**	**4284**	**7902**	**44**	**25**	**8**:1
Chamber 2 Mackerel	6.4	46.0	22.1	3223	6090	36	36	16:1
Chamber 4 Mackerel	6.2	46.7	17.2	4553	6003	41	26	15:1
Chamber 6 Mackerel	6.4	46.0	20.5	2720	5913	37	30	15:1
Mean Mackerel	**6.4**	**46.2**	**20.0**	**3499**	**6002**	**38**	**31**	**16**:1

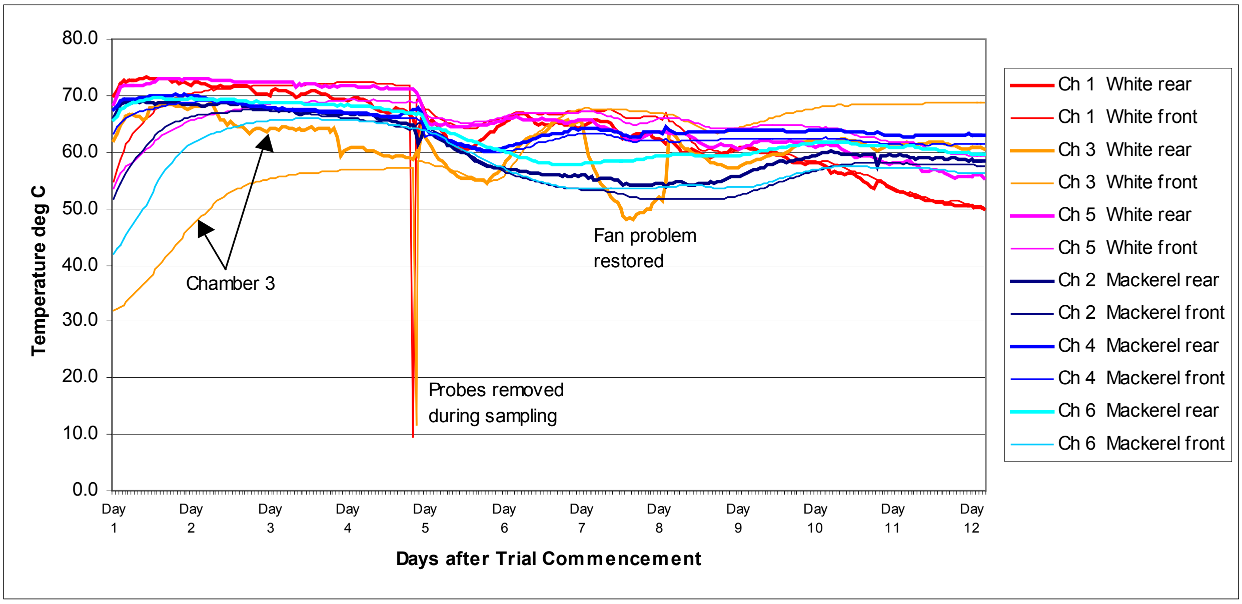
The nitrogen levels followed the pattern of the higher nitrogen content in the white-fish. The overall samples/mixes of the white fish or mackerel in terms of phosphate and potash were very similar.

The ash content reflected the higher inclusion of inert material in the green waste. The carbon contents generally reflects the fact that the mackerel has a high starting carbon content. The C:N ratios directly relate to the higher nitrogen in the white fish and the higher carbon in the mackerel.

The heavy metal values (Pte's) in the sea-food were found to be very low in relation to PAS100 standards where-as the green waste shows Pte's were present at a level of around 20% of the PAS100 threshold. The C:N ratio of the Green Waste was slightly lower than typical. The white fish had the lowest C:N ratio, i.e. presented the highest nitrogen but only modest carbon; where-as the mackerel had significant nitrogen and also the highest carbon content (~ 3 times that of green waste).

The feedstock mixes were prepared and loaded to the various chambers. Temperatures quickly climbed to levels in excess of 65 deg C for all probe locations in the chambers, except for Chamber 3 in the middle and rear of the chamber. After the sixth day all the temperatures were at this level.

Figure 2: General temperature curves for the White–fish and Mackerel Composting trial



The effect of these temperature variations in Chamber 3 were borne out in the pathogen sampling and testing, where in Table 6 it can be seen that at day 4 there were still pathogens present in Chamber 3 where-as they were destroyed in all other samples.

Table 6: Comparison of Microbiological Results of White–fish and Mackerel trial at start of trial and after 4 days

cfu/g mean of 3 sub-samples		Clostridium perfringens As loaded	Clostridium perfringens At 4th day	E Coli As loaded	E Coli At 4th day
Chamber 1	White Fish	3.3×10^{4}	<10	8×10^{5}	<10
Chamber 2	Mackerel Fish	6.2×10^{3}	<10	3.4×10^{5}	<10
Chamber 3 front	White Fish	1.2×10^{4}	<10	7.1×10^{5}	<10
Chamber 3 middle	White Fish	4×10^{3}	3.9×10^{4} *	4.2×10^{5}	<10
Chamber 3 rear	White Fish	4.8×10^{3}	8.3×10^{3} *	7×10^{5}	<10
Chamber 4	Mackerel Fish	9.7×10^{3}	<10	7.7×10^{5}	<10
Chamber 5	White Fish	1.3×10^{4}	<10	3.2×10^{5}	<10
Chamber 6	Mackerel Fish	3.7×10^{3}	<10	3.2×10^{5}	<10

*N.B. Samples in middle and rear were only ones to show pathogens still present; this ties in with poor temperature achievement in these zones of composting chamber 3.

The C:N ratios, followed different trends (see Figure 3). It appears that the white fish C:N ratio first reduced quite steeply in the first four days, continued to fall for the next 10 days and then steadily rose to end at a level higher than where it started. The mackerel, by comparison appeared to follow a trend that gradually decreases over the period with a slight increase at the end.

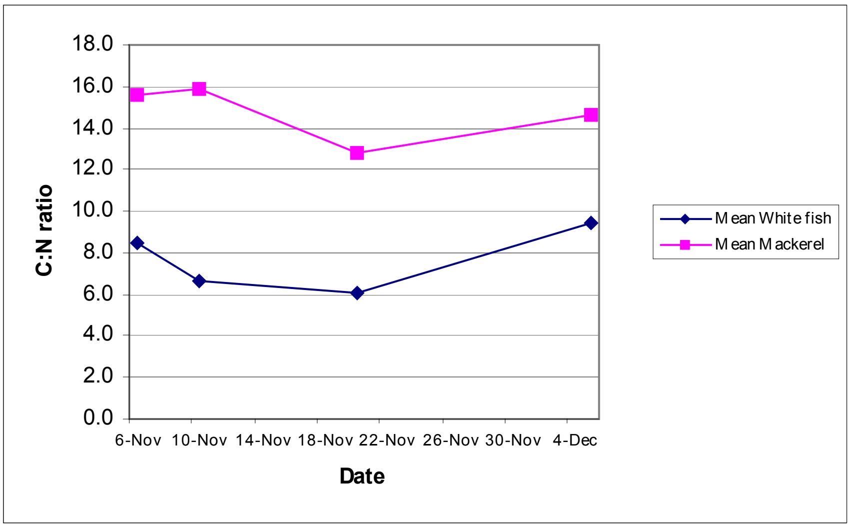
The regime for oxygen control was set to provide minimum levels of 14% which were then restored to 18% by forced air inlet when required. Some minor ventilation was allowed to occur via the air input induced by the suction effect of the wet-scrubber/bio-filter exhaust fan.

The dry matter values were widely different to start with (white fish 36%, mackerel 46%) but both treatments followed a steady rising trend toward terminal dry matter value of 65%.

Where-as both treatments had nearly the same starting pH, and in both treatments the pH followed a rising trend, the white fish pH rose faster initially and sustained a higher pH through to termination, when the final pH reached a level of 8.8 compared to the mackerel at 7.4. This would have been due to the ammonia released from the greater nitrogen content of the white fish.

For C:N ratio to rise during composting is unusual, but only possible if nitrogen or some other element is emitted from the process as ammonia or leached out as nitrate. Given the low dry matter of the white fish and its high nitrogen content, both of these effects may have occurred in the white fish treatment. The trend line for reducing nitrogen in the white fish is steeper than the reducing carbon trend and is typical of such a low C:N ratio feedstock trend in composting.

Figure 3 : Trend for Process C:N Ratio during the White-fish and Mackerel fish Composting trials



Some further consideration in regard to the Mackerel carbon affects may be useful as it appears that there is some irregularity in the samples for this aspect and where-as the nitrogen values in the mackerel treatment stay near level through the trial, it is the organic carbon that shows much greater variation between samples and replicates.

Conclusions – White Fish and Mackerel Trial

- The increase in pH is typical during composting and adds to the likely liberation of ammonia.
- White fish based feedstocks have elevated nitrogen values and the probability of nitrogen losses is increased. A greater inclusion of carbonaceous material would mitigate such losses.
- White fish feedstocks are likely to be wetter (low dry matter), and with composting, there is greater probability of leachate being released
- Composting temperatures based on green waste with white-fish or mackerel are capable of exceeding 70 degree C but this may be difficult to ensure in all parts of any given composter.
- The basic pathogens are destroyed by the composting process, when it has operated at near 70 deg C for 4 days, but some are not destroyed where the temperature only reaches 40 – 50 deg C for this time.

4.3 SHELL FISH AND MIXED FISH COMPOSTING TRIALS

The shellfish and mixed fish composting trial started on 12th December and was completed on 21st January (total of 40 days in the system).

Four different types of shellfish were used (crab, whelks, mussels and *Nephrops*) and two types of fish: oily fish (mackerel) and mixed whitefish (cod, haddock etc). Shellfish waste comprises shell and flesh waste – not just shell on its own. Mackerel waste included all parts of the fish except the fillet. The whitefish waste largely comprised fish frames, with some fish heads.

1.106 tonnes of shellfish (comprising the four types in approximate equal parts) were mixed with 1.404 tonnes of mackerel and 1.156 tonnes of whitefish (total of 3.666 tonnes of seafood). This mix was then combined with about 10 tonnes of green waste, thoroughly mixed and was loaded into three of the composting chambers. Similarly a shell-fish mixture was thoroughly mixed with another 10 tonnes green waste and loaded to the other 3 composting chambers. Giving approx. 1200kg of seafood mixed with 3400kg of green-waste in each chamber.

Shell Fish and Mixed Seafood Analyses

As identified in the preliminary trial, the most notable feature was the high levels of zinc and cadmium in the whelk waste. The zinc was nearly 50% higher than the PAS100 standard for compost and the cadmium was 160% of the PAS standard.

All the sea-food types had elevated nitrogen content, with Nephrops, crab, mussels and mackerel being similar and white fish containing at least twice as much as the others (dry matter basis).

The C:N ratios were quite low in all cases (lowest being white fish C:N = 3:1) and even the green waste was relatively low, being less than the ideal levels for composting.

Table 7: Analytical Results of Shell–fish, White-fish and Mackerel Prior to Composting Process

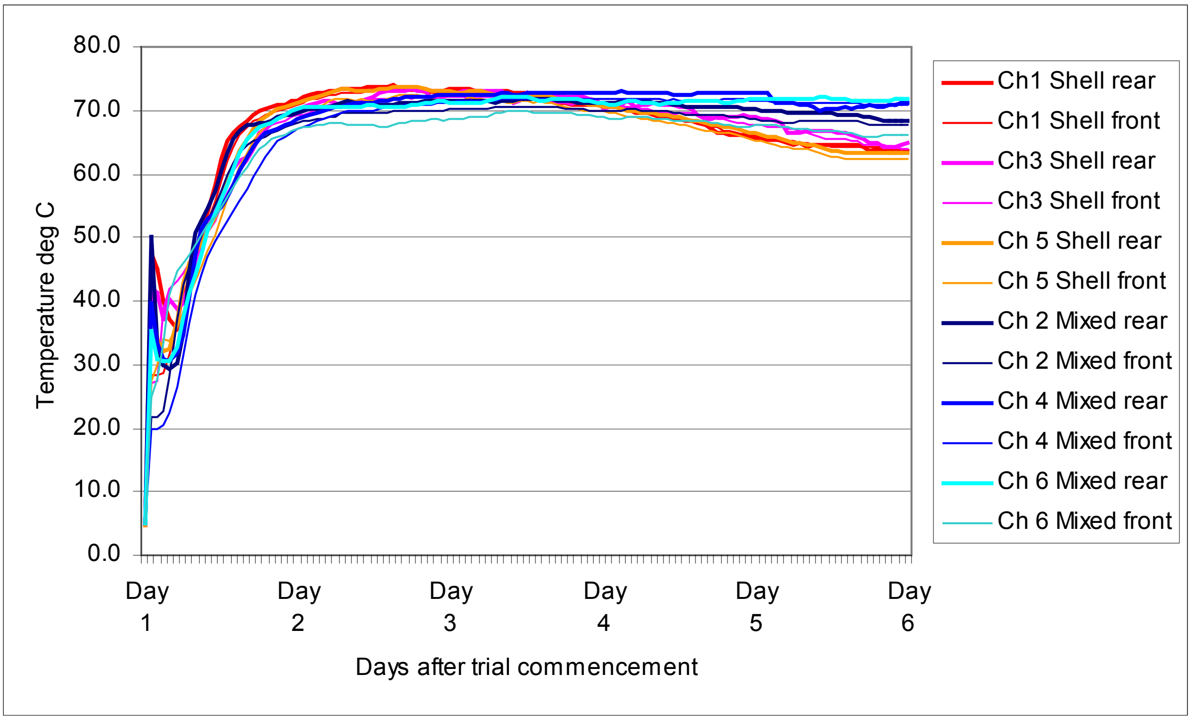
Parameter	Units	Whelks	Nephrops	Crab	Mussels	Mackerel	White Fish	Green Waste
pH		7.8	7.9	7.9	4.9	6.5	6.7	7.1
Oven Dry Matter,	g/kg	781	266	531	543	431	255	443
Total Nitrogen (Kjeldahl),	g/kg, 100% DM	7.1	47.5	34.9	39.7	56.9	110	10
Total Phosphorus,	mg/kg, 100% DM	899	15800	11600	930	16300	47600	1333
Total Potassium,	mg/kg, 100% DM	1750	4820	2010	1620	3180	10400	5003
Total Ash %,	100% DM	96.1	52.6	71.4	80.4	9.6	28.7	35
Organic Carbon,	% m/m, air dried	6.53	13.8	22.9	21.4	31.9	36	17
Total Magnesium,	mg/kg, 100% DM	1020	8120	13200	830	1020	1690	2580
Total Lead,	mg/kg, 100% DM	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	38
Total Nickel,	mg/kg, 100% DM	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	<1.0	14
Total Zinc,	mg/kg, 100% DM	586	17.6	34.8	12.2	51	58.3	115
Total Cadmium,	mg/kg, 100% DM	3.93	<0.25	<0.25	<0.25	0.34	<0.25	1
Total Chromium,	mg/kg, 100% DM	1.71	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	17
Total Copper,	mg/kg, 100% DM	19	7.3	7.56	1.48	2.4	1.16	22
Total Mercury,	mg/kg, 100% DM	0.1	0.03	0.11	0.01	0.1	0.14	0.1
Ammonium-N,	mg/kg, 100% DM	1900	8580	3960	1520	5040	9110	99
C:N Ratio		9	3	7	5	9	3	17

The green waste was much the same as that used in the white-fish/mackerel trial. It was of high bulk density (more weight per unit volume), and wetter, due to the greater inclusion of shredded leaves.

Specific points arising from this were: The starting pH's are influenced by shell inclusion with the shell inclusive treatments showing a pH at, near to, or just above neutral where-as the complete mixes tended to be just below neutral. The dry matters reflected the influence of the fish in the mixes and in both treatments were near the ideal starting moisture levels for composting. The nitrogen levels followed a pattern revealing the higher nitrogen content in the mixture of fish where the high nitrogen value of the white-fish has a significant effect. The basic ash content reflects the higher inclusion of inerts in the green waste as well as the effect of the shell within the shell-fish mix. The carbon contents are generally as expected except for the mackerel, which was significantly higher and this correlated with the lower ash content and the fact that mackerel has a high basic carbon content. The C:N ratios were relatively low due to the nitrogen in the fish but there appeared to be good uniformity between the treatments.

Within 24 hours of the trial starting, temperatures reached in excess of 60^{o}C with the majority reaching just over 70^{o}C, see Figure 4

Figure 4: Temperatures in the Shell and Mixed Fish Composting Trial



The regime for oxygen control was set to maintain oxygen levels in the range ~ 14% to 18% with higher levels being avoided to preclude over cooling. Some minor ventilation was allowed to occur via the air input induced by the suction effect of the wet-scrubber/bio-filter exhaust fan. This trial was continued until a cooling down was observed and the material became more stable.

The microbiological results (Table 8) showed that it was the green waste that was primarily responsible for seeding the pathogens (E.coli and Clostridium perfringens) into the feedstock and into the trial. The average temperatures, ranging mainly between 65-70^{o}C, provided very good pathogen destruction in all treatments and replicates.

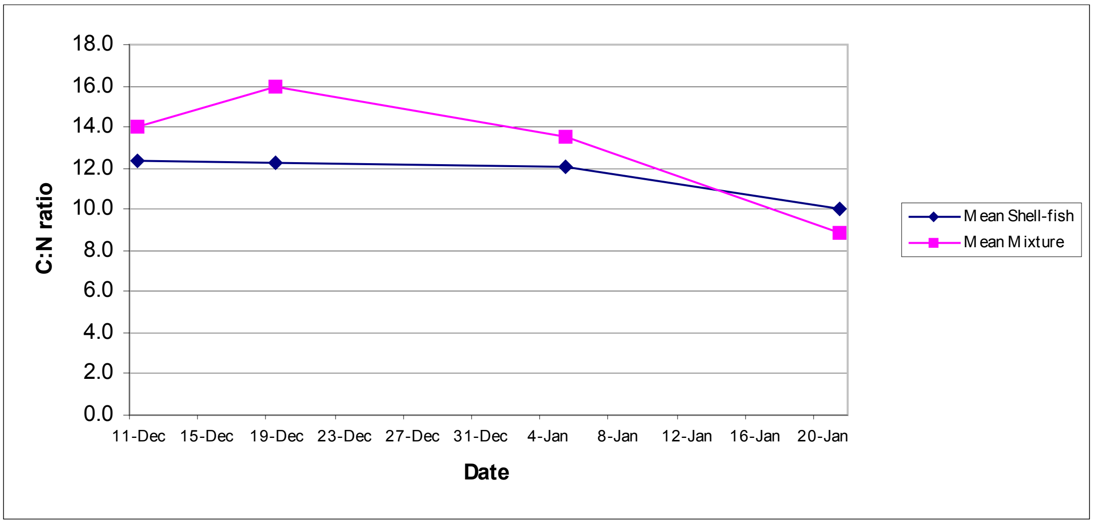
Table 8: Results of microbiological analyses from the Shell-fish and Mixed fish Composting trials

Timescale	Microbiological results (cfu/g)			
	Clostridium perfringens	E. Coli	Enterobacteriaceae	Salmonella
Day 1 – Initial loading	$10^2 – 10^4$	$10^4 – 10^6$	$10^3 – 10^5$	Not detected

Day 4	<10[1]	<10[1]	<10[1]	<10[1]
Day 24	<10[1]	<10[1]	<10[1]	Not detected

Both treatments followed almost identical trends for pH, and dry matter values through the composting process steadily rising toward terminal pH of 8.5 and dry matter value of circa 70%, although the mixed fish compost reduced slightly at termination.

Figure 5 : Trend for Process C:N Ratio during the Shell-fish and Mixed Seafood Composting trials



The C:N ratios, followed different trends. It appears that the shell fish C:N ratio hardly varied until half way through the period, when it started to decline steadily. The mixed seafood trend-line was much steeper once the C:N ratio started to fall and ended lower than the shell fish. As before, in the white-fish composting trial, the C:N ratio rose initially and though this was most likely associated with an initial emission of ammonia or nitrate, the nitrogen graphs suggest that the carbon was elevated and the nitrogen remained steady but rose later in the trial. The relevance of this deserves closer inspection.

Conclusions Shell-Fish and Mixed Sea Food Trials

- Some species of shellfish, in this case whelks, were notable for containing elevated levels of cadmium and zinc. However the levels were such that they were well within industry standards on completion of the trial.
- All seafood types contain useful nitrogen with white fish being twice that of any other.
- Composting temperatures based on green waste with shell or mixed fish were capable of exceeding 70 degree C very quickly
- The basic pathogens were destroyed by the composting process, when it has operated at near 70 deg C for 4 days.

3.4 COMPOSTED PRODUCT QUALITY ASSESSMENTS

The pH values in the composted materials were variable and apart from the mackerel based material tended to stabilise at a very high level of pH 9.

Table 9 shows the final materials compared to PAS 100 standards. The materials were all within the standard despite the initially elevated levels of some pte's in some of the initial feedstocks.

Table 9: Composted Fish Waste/Greenwaste materials compared to PAS100 Standards

Potentially Toxic Elements (mg/kg)		Type of composted material			
	PAS100	**Shellfish**	**Mixed seafood**	**Whitefish**	**Mackerel**
Total Copper as Cu	<=200	26.8	20.1	36.5	25.8
Total Zinc as Zn	<=400	161	132	127	116
Total Lead as Pb	<=200	29	42	52	41
Total Nickel as Ni	<=50	10.4	12.4	17.8	16.9
Total Chromium as Cr	<=100	14	14.3	19	17.1
Total Cadmium as Cd	<=1.5	0.98	0.54	0.39	0.53
Total Mercury as Hg	<=1	0.12	0.09	0.1	0.07

The macro-nutrients N, P and K

N (nitrate plus ammonium – N) should not exceed 250mg/l of which the ammoniacal N should be less than 100mg/l and preferably lower than 50mg/l.

For Phosphorous a maximum of 18mg/l is recommended for sensitive plants. Potassium should be retained in the index range 2 to 6 (i.e. 120 – 1000mg/l or so).

Table 10: Interpretation of Seafood based composts as growing media. (all as mg/l except where stated)

	Reference	**White-fish**	**Mackerel**	**Shell fish Only**	**Mixed Sea-food**
Electrical Conductivity (water extract)	300 micro seimens/cm	1197	1271	960	861
Water Extractable Nutrients					
Ammonium-nitrogen	100 or ..<50	387	503	166	301
Nitrate-nitrogen	none	< 5	< 5	< 5	<5
Total mineral nitrogen	250	392	503	167	303
Calcium as Ca	none	82	88	75	59
Chloride as Cl	Ideally less than 100mg/l	832	817	839	598
Phosphorus as P	18mg/l	35	23	32	30
Potassium as K	120 – 1000mg/l	772	767	474	436
Magnesium as Mg	none	12	23	17	9
Sodium as Na	< 100	209	277	378	213

The summary of data in the Table 10 identifies the conductivity, the sodium, chloride, and ammoniacal salts as being the most limiting factors within these materials and generally precludes their use as growing media for horticultural purposes.

The bulk densities were good and the moisture content values were also low enough to reduce the incidence of further adverse decay or degeneration. In the instances of the fish-only samples the electrical conductivities were very high and well beyond the acceptable range for use as growing media. Mixes where shells were included have also returned high conductivity values. Levels of >700 are regarded as high and over 1000 is regarded as damaging. A level of <300 is preferred.

In the bioassays that followed, the materials were necessarily diluted down with peat in order to reduce the adverse electrical conductivity affect. The Bioassays entailed the generation of a seedling growing medium based on the composted material being blended with horticultural peat to reduce its electrical conductivity strength. For each material, two trays each with 10 tomato seeds sown to the medium are held in the glasshouse under controlled conditions. The bioassay observes, measures and evaluates the germination, emergence, rate of growth, vigour and weight gain in a given period. The test trays are compared to control (peat) based trays for which the measures are used as an index. The principal aim of the bioassay is to ascertain any phytotoxic activity or other negative effect that the material may present to the growing seedling. Tomatoes are used as they are responsive to such effects.

The bioassay results confirmed the evidence of the analytical data.

The bioassay results are summarised below

Table 11: Interpretation of Sea-food based compost Bioassays.

	White Fish Compost	**Mackerel Compost**	**Shell fish Compost**	**Mixed seafood Compost**
Stability mg CO2/gV/d	15.8	35.2		
Dilution required (to bioassay) parts peat:compost	2	2	2	2
Weeds per litre	0	0	0	0
% germination after 14 days	72%	72%	89	106
% germination after 28 days	80%	70%	94	106
Vigour (0-10scale, control 5) @ 14 days Tray 1 & 2	4 & 4	2 & 4.5	4 & 4	5 & 5
Vigour (0-10scale, control 5) @ 28 days Tray 1 & 2	2.5 & 2.5	2.5 & 3	4 & 4	3.5 & 4
Phyto-toxicity score (0-10scale, none visible to dead)	3	3	1	1
Seedling fresh weights at trial end Weight per tray and (wt per plant g)	Per tray (plant)	Per tray (plant)	Per tray (plant)	Per tray (plant)
Control 1	8.07 (0.81)	8.07 (0.81)	12.4 (1.55)	12.4 1.55
Test tray 1	2.88 (0.36)	2 (0.4)	7.38 (0.82)	6.57 (0.73)
Control 2	6.2 (0.62)	6.2 (0.62)	12.2 (1.22)	12.2 (1.22)
Test tray 2	2.08 (0.26)	3.51 (0.39)	8.08 (1.01)	9.6 (0.96)
Ratio Test tray to control 1 *	0.36 (0.44)	0.24 (0.49)	0.6. (10.52)	0.53 (0.47)
Ratio Test tray to Test tray 2 *	0.33 (0.42)	0.57 (0.63)	0.66 (1.01)	0.79 (0.79)

* These values have been calculated to show the level of performance as a percentage compared to the control trays.

Conclusions from PAS100:2002 tests and BIOASSAY

Each of the Sea-food waste based compost materials has shown negative effects and poor performance where it has been used in the role of a 'growing media' for horticultural purposes.

The key factors arise owing to the combination of green waste and fish waste. They are:

1. High electrical conductivity owing to ammonium, sodium and chloride salts
2. Phyto-toxicity effects, potentially from mould growth in some instances.
3. The need to be diluted with peat. Typical, but an undesirable feature.
4. Variability: typical and remedy is expensive mechanical treatment
5. Odour. Undesirable for close use, manual handling in confined spaces.

Sea-food waste Composts in the role of 'Topsoils'

It is significant that the white fish based material fell within the standards and thresholds for 'Premium' topsoil (although it cannot be classed as Premium as it was not an original topsoil).

For the other materials, various parameters including pH, texture and Exchangeable sodium percentage were identified as reasons why higher classes were not reached. Some of these aspects could be resolved, e.g. screening or crushing in order to reduce 'stones' and in commercial practice the crushing of the shells may be a major benefit in this regard. Excess pH may be due to ammonia being evolved from the high nitrogen of the sea-food waste – undesirable as a growing media, but useful when used as a soil conditioner.

Exchangeable sodium is not a major issue but does have consequences for the structure of soil as it tends to cause dis-aggregation of soil particles and can lead to sedimenting and de-structuring of soil with the effect of blocking air and water movement and leading to poor drainage, stunted root growth and droughting off of plants.

It may be concluded that as admixtures into soil making materials, these composted waste materials may be ideal, especially if screened first, or used in the types of use defined earlier as economy grade topsoils

SECTION 5.0 COMPOSTED PRODUCT USAGE (GROWING) TRIALS

5.1 INTRODUCTION TO THE GROWING TRIAL TECHNIQUE

5.1.1 Aim of the Growing Trial

The aim of the growing trials was to simulate the effect of using the composted seafood materials as if they were being used in agriculture as soil conditioner and fertiliser type products.

The trials were carried out in controlled conditions in the glass house as replicates within the various treatments and compared against control soil materials using the same basic soil as the treatment.

A large batch of good quality topsoil was mixed and blended until it was as uniform as possible. The soil was apportioned to plant pots (7" pots) and some basic fertilisers added to ensure basic nutrient requirement can be met.

Six different types of seafood compost were used. Two came from the initial pre-trial study and included mixed seafood in a low C:N ratio (9:1) (from hereon called Chamber 1 rear) and mixed seafood compost in a higher C:N ratio (15:1)(from hereon called Chamber 3 rear). The other four composts included samples taken from the output materials of the main trials; whitefish only, pelagic fish only, mixed shellfish and mixed fish and shellfish.

The materials (composted seafood waste products) were prepared, added to the plant pots and blended into the soil using a small trowel/fork. This was to simulate the cultivation that a farmer or grower would undertake. The levels of addition of the products were carefully calculated for each treatment. Given the needs for expediency, some of the data were based on previously available data and therefore validation tests and adjustments were necessary later.

5.1.2 Growing Trials.

For each rate, separate seven-inch pots were planted or sown with 3 tomato seedlings or 25 barley seed.

Tomatoes were used as they are more sensitive to Phyto-toxicity and reveal symptoms of nutrient shortage or other adverse conditions more clearly. Barley was selected as being representative of the cereal type crops that would most likely be the receiver of this material in practice.

The pots with barley seed were covered during seed germination and up to emergence.

Figure 6: Photograph of Growing Trial within Glass-house

During the growing trial period the plants were kept in a carefully controlled regime of temperature, lighting and watering. Watering was done via capillary matting.

Growth was then observed in a heated glasshouse over the following 56 days. Recordings of plant measurement were made at various stages of plant growth. and Plant vigour was assessed at the same time by using a 'scoring system' that included criteria for plant bushiness, colour and grow.

Records of the actual plant numbers established were compared with the 25 seed sown as well as being compared with the 'control'. In nearly all cases, the treated pots performed better than the control pots and in all but one instance the overall establishment percentage was over 90%, i.e. only

reduced to 23 out of the 25 potential plants. Where the percentage was less than 90% (i.e. dropped to 22 plants), this occurred in the treatments for white-fish compost, but notably, the control only gave 23/25 plants established. However, the Mackerel Compost, against the same control, did return a better plant establishment percentage.

It may be concluded that the establishment of the barley seed was not adversely affected by the compost admixtures and there may be some evidence to say that establishment was enhanced. The reason for this may not have been nutrients, but could have been a small improvement to soil structure due to the additional organic matter in the compost.

At the termination of the growing trial, (56 days), the barley and the tomatoes were ‘harvested’ by trimming the plants off at ground level. The plants were then weighed to give their ‘fresh’ weight, inclusive of moisture content.
For the tomatoes, there was a definite trend for the treated plants to generate circa 50% greater weight than the control in relation to nitrogen applications in the compost of over 180kg/ha with 2 exceptions, being the white-fish compost and the mackerel-fish compost.

Vigour Scores for Chamber 1 Rear Compost
There was no effect of the Chamber 1 composted waste upon plant emergence, all of the barley emerged and was similarly vigorous throughout the growing trial. The 2 high rates of tomatoes began by being slightly less vigorous than the other rates, but by the end of the trial they were slightly more vigorous, as was the 200-kg/ha rate. Furry mould did appear on the surface of the soil at first but soon disappeared. The 300 kg/ha barley suffered mildew and this was soon eradicated.

Vigour Scores for Chamber 3 Rear Compost
There was no effect of the Chamber 3 composted waste upon plant emergence and the barley remained similarly vigorous throughout the bioassay. One of the 400 kg/ha tomato plants senesced and was replaced soon after being planted. The tomatoes remained similarly vigorous throughout the bioassay. Furry mould did appear on the soil surface at the beginning but soon disappeared. Scores for vigour of the treated pots were significantly better than the control during the mid trial, but at termination everything was more standardised.

Vigour Scores for White-fish Compost
There was no effect of the white fish composted waste upon plant emergence, most of the barley emerged and the plants with higher rates of waste became more vigorous than the control plants as the bioassay progressed, as reflected in the fresh weight figures. Although one of the 100 kg/ha tomatoes senesced when first planted and was replaced, they remained similarly vigorous throughout the bioassay The 200, 300 and 400 kg/ha plants were the most vigorous through to the end of the trial.

Vigour Scores for Mackerel Compost
There was no effect of mackerel based composted waste upon plant emergence. The barley remained similarly vigorous throughout the bioassay, with the 300 and 400 kg/ha rates being slightly more vigorous than the control plants. The tomatoes were also similarly vigorous throughout the bioassay with the 300 kg/ha plants being the most vigorous as reflected in the fresh weight figures. The 100 and 200 kg/ha tomato plants were slightly less vigorous than the control during the final stages of the trial.

Vigour Scores for Shell-fish Compost
There was no effect of shell-fish based composted waste upon plant emergence. The treated tomatoes and the barley were actually more vigorous than the control plants throughout the trial and also at the final stages as was reflected in the fresh weight figures at termination.

Vigour Scores for Mixed-Fish Compost
There was no effect of mixed based composted waste upon plant emergence. The barley remained similarly vigorous throughout the bioassay, with the higher rates being the most vigorous. The

treated tomatoes were slightly less vigorous than the control plants at the beginning of the trial but towards the end increased in vigour with the 200,300 and 400 kg/ha plants being slightly more vigorous than the control plants during the final stages.

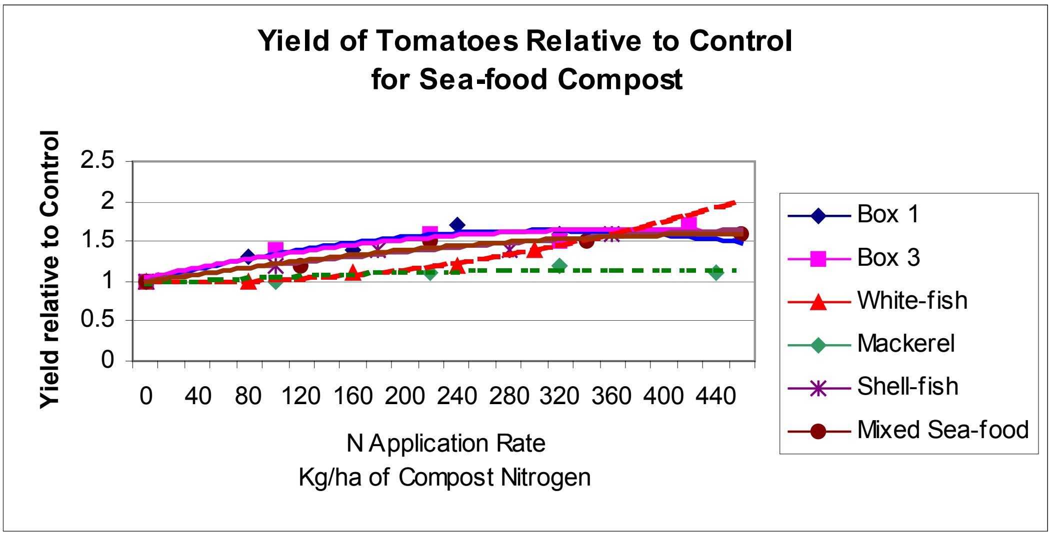
Evaluation of Final Yield of Plant Matter Under Trial

At the termination of the growing trial, (56 days), the barley and the tomatoes were 'harvested' by trimming the plants off at ground level. The plants were then weighed to give their 'fresh' weight, inclusive of moisture content. For ease of comparison, the data has been represented by the specific weight of the plant at termination, as referenced to the control within that series. I.e. the control end weight is taken as 1, and all other plant weights are indexed to that weight. This allows all of the curves to be charted with the same origin and scale.
Owing to the 'actual application rates' being varied, for this analysis, the results have been charted as weights against actual application rate rather than 'target rate'. For convenience of charting, the 'actuals' were rounded to the nearest 10kg/ha.

The charts have been drawn using polynomial expressions to produce smoothed curves as the means of identifying trends.

For the tomatoes (Figure 7) there is a definite trend for the treated plants to generate circa 50% greater weight than the control in relation to nitrogen applications in the compost of over 180kg/ha, with 2 exceptions being the white-fish compost and the mackerel-fish compost.

Figure 7: Tomatoes Fresh Weight at Termination Relative to Control

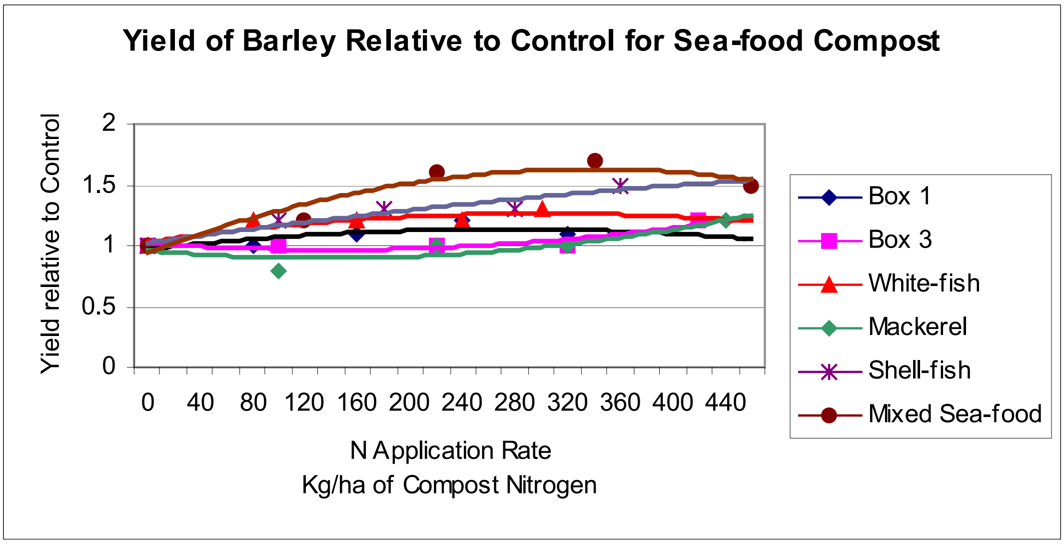


It will be noted that the white fish 'actual' nitrogen rates were significantly lower than the target rates due to the variations in compost material between sampling and screening for use. This also means that the curve produced is necessarily extrapolated further forward than ideal.

The Mackerel compost also shows variance from the trend and follows a much straighter curve than the others at a much lesser angle. This is clearly linked with the reduced vigour in the tomatoes during the final 2 weeks of the trial for the 100 and 200kg/ha plants and also poorer early (28day) vigour in the 400kg/ha plant.

The barley (Figure 8) shows much less defined trend and most notable are the negative trend lines of the Mackerel and Chamber 3 compost materials.

Figure 8: Barley Fresh Weight at Termination Relative to the Control



SECTION 6.0 DISCUSSION OF COMPOSTING AND GROWING TRIALS

6.1 DISCUSSION OF COMPOSTING TRIALS

Generally the results of the composting trials followed an expected pattern and has provided extra confidence levels in regard to the sanitisation of sea-food waste and green-waste at the time and temperature levels already cited in references and in regulations. The temperature curves followed typical patterns once the system was properly operational and the pathogen destruction was also predictable by comparison to standard texts and references. The project provided several items of useful procedural detail that can be utilised to add to the existing information pool to be used for the benefit of the composting industry. This will be equally useful for the composting of green waste as for sea-food waste but will be more useful in the context of the composting of high nitrogen materials.

On the basis of the information generated form this work, a regime of attaining 70 deg C for the first 4 days (or less, if the EU guidance is followed) followed by controlled temperature composting at the optimum 55 deg C would be ideal. The material should ideally be conditioned and matured using forced air (low volume) ventilation to maintain aerobic conditions through the cooling phase.

Use of a fully enclosed system in order to establish verifiable and uniform temperature control does not mean that process management can be relaxed and would appear to be essential.

Initiating the composting process using high moisture content material is clearly beneficial, and the policy of restricting exhausted air in order to retain moisture within the system was found to be very important. Premature drying out is a problem as it leads to premature cessation of composting and a dusty hazardous end product. Adding water late in the composting process is not ideal due to the cooling effect and risk of leachate generation. Leachate recirculation during the later stages is not recommended for similar reasons plus the risk of re-inoculation of pathogens.

6.2 DISCUSSION OF PLANT GROWING TRIALS

The growing trials followed a fairly typical pattern, though the response rate for barley growth at the greater rates of application based on the added nitrogen supply was disappointing.

Barley establishment was better than control. This is not uncommon and the effect is put down to the increased organic matter providing better moisture in the surface of the soil and therefore better germination. The poorer vigour in the higher mackerel rates of application in the tomato crop growth was noted. It was apparent that there was some inhibition from the mackerel based compost materials and this may have been due to the combined effect of the oil content and the relative immaturity of the compost. The inhibitive effect to growth was clearly evident and the presence of blue mould growth on the soil surface of the mackerel based compost pots was an obvious indicator of some phytotoxic effect. The same effect was noticeable in the bioassay.

In the bioassays where the germination/establishment was much poorer than in the growing trials the difference is readily explained by the order of magnitude difference in the application rates that were used in each case; i.e. the bioassay dilution was 1 part compost to 2 parts peat where-as in the plant pot growing trial the ratio was 1:32 compost to soil.

Overall, the results of the growing trial have confirmed that the materials as produced from the blend of green waste with seafood waste can give beneficial effects to plant growth within limits and pending full and proper composting should be suitable for use in field scale agriculture.

SECTION 7.0- INDUSTRY CONSIDERATIONS

7.1 COMPOSTING INDUSTRY TECHNOLOGY REVIEW

Despite changing legislation, there are still a number of options that are available to enable the diversion of fish-waste from increasingly expensive and undesirable landfill, rendering or basic incineration. Low carbon composting (Bioganix), Anaerobic Digestion (Holsworthy, Greenfinch, Chris Reynells, Biffa -Leicester) and aerobic in vessel composting systems (various; includes Gicom, Horstmann, Wright, Alpheco, Neales etc.) together with some other systems will be of merit and should be capable of attaining permission under the Animal By-product Regulations. However, due to the relatively low financial value of composted fish-waste (i.e. minimal revenue potential), the process of composting will be seen as a cost minimisation option and therefore low cost operations will be sought-after.

Seafood-waste generators will aim to identify routes and destinations for disposing of seafood waste that are low cost. Low cost composting operations, could provide a cost competitive route for seafood-waste removal.

Composting Industry Techno-Economic Consideration

The most important criteria that will affect industry selection of fish-waste treatment is financial.

As landfill costs rise to a minimum of £15/t gate-fee plus £18 - £35/t landfill tax; and on the basis of the animal by-products Regulation, seafood waste cannot be directly landfilled, then composting options at around £55 - 70/t would be a viable alternative.

Conclusions Regarding Composting Industry Consideration

The most likely prognosis is that the ‘waste management industry’ will provide the facilities and service for multi feedstock facilities and that sea-food waste will be one component of such a process.

Where the sea-food industry is so minded, then acquisition of green waste or preferably catering waste composting contracts, should be the aim, where-by the seafood waste composting can be largely funded within the co-composting operation.

SECTION 8.0 - CONCLUSIONS AND RECOMMENDATIONS

8.1 PROJECT CONCLUSIONS

The project has shown that all seafood waste types are high in nitrogen.

The project has shown that composting at temperatures of around 70deg C for 4 days provide the necessary levels of pathogen destruction in fish and green waste based mixed feedstock. The trials did not include consideration of whether composting at 70^{o}C for a lesser period of time has the same result (though this is the current minimum legal standard).

The project has shown that mixes of feedstocks that are higher than 1:3 (seafood to green waste) in seafood-waste content, are liable to experience problems during composting, may produce excessive emissions and will produce high nitrogen compost materials that are difficult to use.

The project has shown that a period of around six weeks in an 'in-vessel' format composter should lead to stabilised material at exit, but that fore-shortening the process is likely to leave the material in an active state that may give rise to uncontrolled emissions and ill-defined product.

The project has indicated that some shellfish waste, notably whelk, have slightly higher levels of some heavy metals However composting with green waste has shown the resultant material is well within the composting industry limits. If these types of materials are to be used, they should be mixed with other materials to ensure any potentially damaging effects are minimised.
The project has shown that subject to Good Agricultural Practice limits for waste derived compost usage in field scale agriculture, there are no adverse affects and there are likely to be some positive affects of using seafood-waste/green waste based compost.

The project has identified some issues in regard to Mackerel based compost and circumstantial evidence would suggest that this is related to the high oil content and related incidence of phytotoxic mould growth. If using oily fish, these should be mixed with other materials to reduce the overall oil content.

The project has shown that composting need not entail highly expensive infrastructure and that management of the process is potentially more important that the structure or container within which the process is carried out. The key management aspects are: feedstock preparation, adequate moisture content (and avoidance of in-process drying); ventilation control (recirculation with minimal fresh air aspiration controlled by oxygen concentration measurement); ease of loading/unloading; air exhaust control; and adequate temperature monitoring and logging through the process.

8.2 PROJECT RECOMMENDATIONS

1. It is recommended that a short feasibility study be prepared to identify the potential for multi-feedstock food/catering waste and fish-waste processing. Linkage with and alignment to existing studies in the food industry should be readily available. It is proposed that areas that currently have difficulties in disposing of their seafood waste be involved. These could include NW England, SW England, Northern Ireland and parts of Scotland.

2. To promote and advertise the positive results of this study to the sea-food industry, especially in the above areas, with the intention of forming local working parties with the aim and objective of either establishing a scheme or joining an existing waste composting scheme.

3. To focus on one of the above areas and take action to help with the implementation of a scheme for composting and utilising fish waste.

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ANNEX 1: PHOTOGRAPHS OF THE SEA-FOOD WASTE COMPOSTING PROJECT

Figure 9 - Photograph of Composting Chambers under construction

Figure 10 – Photograph of woodchip and bark bio-filter facility during construction

Figure 11 - Photograph Green-Waste and Feedstock Mixing Machine

Figure 12 – Photograph of Mixed Sea-food and Green-Waste being discharged from the Mixing Machine

Figure 13 – Photographs of Crab shell & plate (top-left), Nephrops (lower left) and Whelk sea-food-waste

Figure 14 – Photographs of Mackerel (above) and White-fish, Sea-food waste

Figure 15 – Photograph of Composted Material after Preliminary Trial	*Figure 16 – Photograph of Tray of Tomato Seedlings during Bioassay*