The importance of dietary EPA & DHA omega-3 fatty acids in the health of both animals and humans

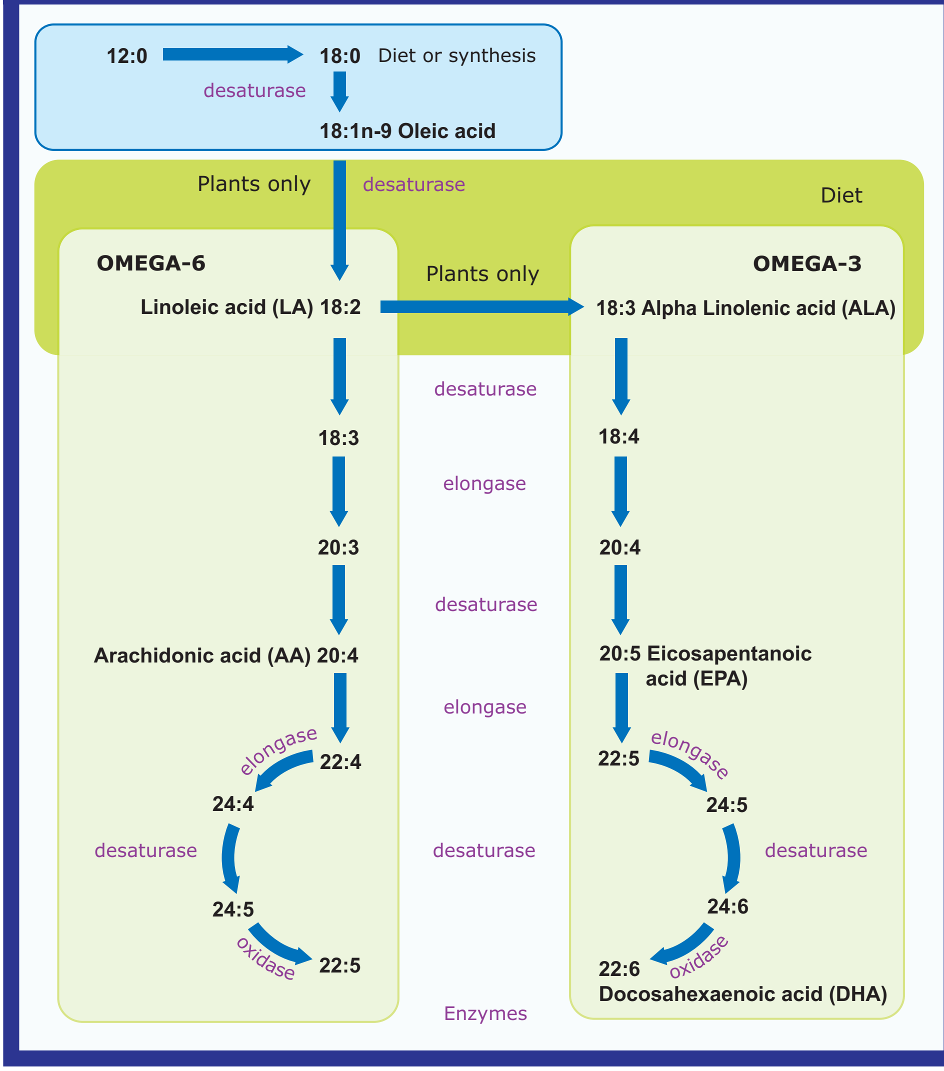
UNDERSTANDING FATTY ACIDS

Fatty acids like amino acids are one of the fundamental building blocks of life. Amino acids are used to make proteins while fatty acids perform a whole range of different tasks in both plants and animals. At the simplest level, fatty acids in the form of oils and fats are a good way to store energy for future use, since weight for weight fats and oils retain more energy than either protein or carbohydrate. For example, plants store energy for seed development in the form of oil (eg rapeseed oil or soya oil) while mammals store energy in the form of adipose fat or cod in the form of oil in their livers.

However, in addition to simple storage, fatty acids play a vital role in many biological structures and functions. Possibly the most important is as one of the fundamental components in membranes. Biological membranes form the walls of all cells, whether simple single-celled algae or complex specialised cells such as nerves, muscle-cells or blood-vessel cells. These membranes must be semi-permeable, allowing passage through of some molecules while restricting the passage of others. The properties of the membrane formed will depend on the nature of the fatty acids incorporated.

Fatty acids come in a variety of forms but all have the common feature of being a chain of carbon atoms. These carbon chains can be only a few carbon atoms long or they can be between 18 and 24 carbon atoms long. The latter are then called long-chained fatty acids and these are the ones that are particularly important for inclusion in membranes.

Figure 1.
Fatty acid family trees



In addition to the number of carbon atoms, the number of double bonds in the chain is also important. The more double bonds there are, the less 'saturated', and the more 'unsaturated', is the fatty acid. And where the first double bond in the chain occurs also affects its properties; if it occurs 6 bonds in from the end of the chain it is called omega-6, while if it is 3 bonds in it is called omega-3.

Plants and animals can synthesise many different fatty acids which perform a wide variety of different functions, the simplest fatty acids so formed are saturated fats such as palmitic acid (16:0 where 16 is the number of carbon atoms and 0 is the number of double bonds). These saturated fatty acids can have additional carbon atoms added and double bonds formed by means of different enzymes to produce a wide range of different fatty acids.

However, only plants can produce fatty acids in the omega-6 and omega-3 series, which is why these have been called the essential fatty acids, see Figure 1. Animals depend on getting these essential fatty acids through their diet. Plants can also convert omega-6 fatty acids into omega-3 fatty acids and vice a versa, whereas animals lack the ability to do this and they must obtain adequate quantities of both types from what they eat. In general, plant leaves and algae are a good source of omega-3 fats while seeds are a good source of omega-6 fats.

As will be discussed later in this datasheet this also means that the fatty acid profile of animals, including humans, will depend on their diet. For example a chicken which has fed on grain or soya oil for much of its life will have much more omega-6 and less omega-3 in its body, than one that has consumed a diet rich in leaf-eating worms and caterpillars.

In many functions of the body omega-3 and omega-6 fatty acids can be interchangeable but, as our knowledge of fatty acid nutrition has increased, it has become clear that, particularly with the longer-chained fatty acids such as arachidonic acid (AA 20:4 n-6) and eicosapentaenoic acid (EPA 20:5 n-3), there are subtle, but very important, differences in how they behave when performing the same function.

EPA & DHA

This datasheet is focused on eicosapentaenoic acid (EPA 20:5 n-3) and docosahexaenoic acid (DHA 22:6 n-3), which are the two main long chain (LC) highly unsaturated fatty acids, or HUFAS in the omega-3 series. They are found most widely in the marine environment where they are produced by algae, particularly in cold waters. These HUFAS are particularly beneficial in cold environments because the longer and less saturated the fat the more liquid it is at low temperatures. This means that when bound into membranes HUFAS keep them much more flexible even at low temperatures. The algae are eaten by zooplankton and the zooplankton by fish and on up the food-chain. At each stage these HUFAs are retained and utilised for their properties.

Throughout this text they are referred to as:

- EPA & DHA
- long chain, or LC omega-3s

Omega-3 can also be expressed as n-3 or Ω3. In this datasheet we will use the n-3 format.

Another type of omega-3 is the shorter chained alpha linolenic acid (18:3 n-3 ALA) which is rich in many plants of both aquatic and terrestrial origin. Animals can convert ALA into EPA & DHA by chain elongation and desaturation but, as can be seen in Figure 1, it is a complicated pathway requiring a number of steps and enzymes. Some animals can perform this relatively efficiently, however other animals, particularly those that would normally obtain significant quantities of LC omega-3s in their diet, have a very low ability to do this. Fish and humans both fall into this category.

LONG CHAIN OMEGA-3S DIRECTLY AFFECT HUMAN HEALTH, GROWTH AND WELL-BEING

The long chain highly unsaturated omega-3s, EPA & DHA, are vital for a wide range of biological functions. They are in every cell of the human body where they directly affect human health, growth and well-being.

For example EPA & DHA are found in the phosopholipid layer of membranes keeping them mobile. Around 25% of the fat in the brain of humans and animals is DHA and this proportion seems to be independent of diet (ref. 1), which would indicate that it plays a very important role in neural membranes. A lot of research now being published shows the benefit of increased DHA intake on brain function. DHA is the preferred fatty acid for the correct construction and functioning of membranes particularly those in very active tissue such as nerves and active muscle.

Milk is one of many food and beverage products which have been supplemented with omega-3 from fish oil

EPA & DHA are both important in the cardiovascular system and EPA in particular plays a part in the anti-inflammatory response. Both omega-3 and omega-6 HUFAs play an important role as precursors of eicosanoids. Eicosanoids are a group of cell messengers made from either AA or EPA that affect blood pressure, blood clotting, immune function allergic response, reproduction and gastric secretion. It has now been found that we need a balance of these eicosanoids, some made from AA (omega-6) and some from EPA (omega-3).

For example eicosanoids made from AA are highly inflammatory (a useful function on many occasions to help defend and repair the body), while eicosanoids made from EPA are much less so. The problem is that if almost all the eicosanoids are made from AA this makes the system highly reactive and on occasion over-reactive, resulting in un-wanted inflammation (as in coronary disease) and allergic responses such as asthma. It is therefore important to have a balance of the two types of eicosanoids (refs. 2 and 3). This explains why EPA is seen to have an anti-inflammatory effect particularly in cases of cardiovascular disease.

THERE ARE MULTIPLE POSITIVE HEALTH BENEFITS FROM THE *LONG CHAIN* OMEGA-3S, EPA & DHA

Increased intake of EPA & DHA has been shown to have multiple health benefits. Below is a list of just some of the conditions where the impact of increased LC omega-3s has been studied and evidence of benefits identified – some preventative and some therapeutic (refs. 2, 5.1, 5.2, 5.5).

Health benefit endorsed by authorities

- Reduced reoccurrence of cardiac infarction (an infarct is death of heart tissue due to blocked coronary arteries)
- Protection against cardiovascular disease

LC omega-3 fatty acids benefit the hearts of healthy people, as well as those at high risk of, or who already have, cardiovascular disease. They make the blood less likely to form clots that cause heart attack and protect against irregular heartbeats that cause sudden cardiac death. Three large control trials have shown reduction in cardiovascular events of 19% to 45% (ref. 2).

Robust or significant scientific evidence

- Cognitive and behavioural development
- Rheumatoid arthritis
- Psychiatric disorders, including depression and schizophrenia
- Recovery from surgery
- Dementia in the elderly
- Psoriasis
- Crohn's disease
- Progression of metabolic disease

Some evidence

- Asthma in children
- Vision
- Averting progression towards Type 2 diabetes
- Behaviour and concentration, including ADHD (attention-deficit hyperactivity disorder) and dyslexia
- Obesity
- Cystic fibrosis and many more conditions

There is also evidence that fatty acid supplementation is efficacious in treating educational and behavioural problems in children with Development coordination disorder (DCD) (ref. 6).

Professor John Stein, Professor of Physiology at Oxford University, is among those who believe there is evidence that it was the inclusion of fish oils in the diet which facilitated the great evolutionary cognitive leap forward by the human race.

THE CONTEMPORARY DIET IS DEFICIENT IN EPA & DHA

Humans require only about 1% of their fat intake to be LC omega-3s. However changes to our diets over the decades mean that most current human diets are now seriously deficient in omega-3s.

Probably the most pervasive theory as to why this has happened is that mankind has reduced its intake of fish and seafood and switched to consuming more processed food containing omega-6 seed oils such as soya, often in partially hydrogenated form. Others point to reduced direct consumption of dark green leafy vegetables and changes to the diets of the animals from which we obtain meat, milk and eggs, which has resulted in them containing much less LC omega-3. At one time, for example, most poultry was free to roam collecting its own food which was more varied and contained a wide range of fatty acids. Chicken and pig diets were also often supplemented with fishmeal containing around 10% fish oil, rich in LC omega-3s. In recent years for economic reasons fishmeal has been withdrawn from most pig and poultry diets and replaced with mainly grains and oilseed meals.

RECOMMENDED INTAKE

For many countries the official recommended daily adult intake of EPA & DHA to lower chronic disease risk is 300 to 650 mg/day. In the UK, for example, it is 450mg/day or 3.15g/week.

John Lee et al in a Mayo Foundation Paper in 2008 (ref. 2) focused on doses for cardioprotection and concluded that the target EPA & DHA consumption levels are:

- 1g/day for those with known coronary heart disease
- 500 mg/day at least for those without the disease
- 3-4g/day for patients with hypertriglyceridemia

ACTUAL INTAKE

Recent studies have put actual average intake at:

- North America 200mg/day (ref. 5.3)
- UK 244mg/day, of which 199mg/day from fish (ref. 5.3)
- Australia (median) <100 mg/day (ref. 4)
- Japan 900mg/day (ref. 5.3)
- Mid European 250mg/day (ref. 5.3)

The risk of contaminants such as mercury, PCB's and dioxins in fish has been a contributory factor in the reduction in the intake of fish in some countries, most notably the US. However, following a number of high profile stories about contaminants in tuna and farmed salmon a number of researchers have looked at the risks and benefits of consuming oily fish. Mozaffarain and Rimm (ref. 7) conducted an in depth study evaluating the risks and benefits of eating fish and concluded that : "......the benefits of fish intake exceed the potential risks. For women of childbearing age, benefits of modest fish intake, excepting a few selected species, also outweigh risks." Following this and a number of other high profile studies, it is now clear that while the risk from contaminants is so low it is difficult to quantify, the benefits from higher EPA & DHA consumption are becoming more and more quantifiable.

THE BALANCE OF OMEGA-6 TO OMEGA-3 IN THE DIET HAS CHANGED

As noted earlier, the rate at which ALA is converted to LC omega-3 is slow and relies on a series of different enzymes. These same enzymes are also involved in the conversion of short-chain omega-6 fatty acids into long-chain omega-6 fatty acids (Figure 1). This means that the more omega-6s consumed the less possibility there is of converting omega-3s to long-chained fatty acids. So not only is it important to consume adequate levels of omega-3s, but it is also important to moderate the intake of omega-6s.

For a long time it was thought that ALA was the essential omega-3 fatty acid, since both EPA & DHA could be synthesised from sufficient quantities of ALA. In many animals that is the case. However, more recent studies have shown that in humans the rate of conversion varies a lot from individual to individual and is dependent on age. However it is on average around a 5% conversion from ALA to EPA and less than 0.5% for ALA to DHA (ref. 8). This means that the consumption of ALA from, say linseed or flax oil, does very little in the way of meeting the dietary need for EPA, and even less for DHA.

Membranes are vital components in all areas of the body and if there is not sufficient DHA to include in the phospholipid layer, the body will make do with other PUFAs, but none of them are as effective. There is now increasing evidence that higher levels of DHA in membranes make them more mobile and porous and this leads to a higher metabolic rate and a more effective uptake of glucose from the blood. The fats in slow animals are more saturated and contain more omega-6 fatty acids than the fats of small fast animals. For example, the fatty acids in the muscle membranes of humming birds is 70% DHA compared to around 6% in an emu (ref. 9). This increased porosity then explains the finding that diets with sufficient levels of DHA can contribute to a reduction in obesity and a reduced incidence of non-insulin dependent diabetes (ref. 10).

The dietary ratio of omega-6s to omega-3s in the developed world diet is currently 10:1 to 20:1, against the medically recommended or optimal ratio of 4:1 or 5:1 and the Palaeolithic hunter/gatherer ratio of 1:1. By reducing the omega-6 to omega-3 ratio, the overall health and wellbeing of the population will increase (refs 11 and 12).

Obesity is now prevalent throughout much of the Western world. This and associated diseases such as cardiovascular disease and type 2 diabetes represent an imminent public health crisis. Moderate increases in our consumption of omega-3 long chain polyunsaturated fatty acids would help avert these problems.

FISH AND SEAFOOD ARE THE PREDOMINANT AND BEST SOURCE OF EPA & DHA

Significant quantities of LC omega-3s are found in a very limited number of foods. Now that few societies eat brains and poultry diets are full of omega-6 fatty acids, marine oils are the only significant dietary source of DHA and the major dietary source for EPA. Data for the United Kingdom show that more than 80% of natural EPA & DHA available for human diets comes directly from fish and seafood (ref. 5.3).

Table 1.
Long-chain omega-3 content of some common foods

Seafoods	mg/100g	Other Foods	mg/100g
King salmon *	> 2000	Enriched foods	Varies
Greenshell/lipped mussels	950 #	Eggs regular	80
Hoki (Blue grenadier)	410	Turkey	30
Gemfish	400	Beef	20
Blue eye cod	310	Milk regular	0
Sydney rock oysters	300	Vegetable oils & spreads	0
Tuna canned	230	Regular bread	0
Snapper	220	Cereals, rice, pasta, etc	0
Barramundi saltwater	100	Fruit	0
Giant tiger prawn	100	Vegetables	0

Source: Fatty acid database, RMIT University, Australia as quoted on www.omega-3centre.com.
* Massey University analysis. # NZ Crop & Food analysis

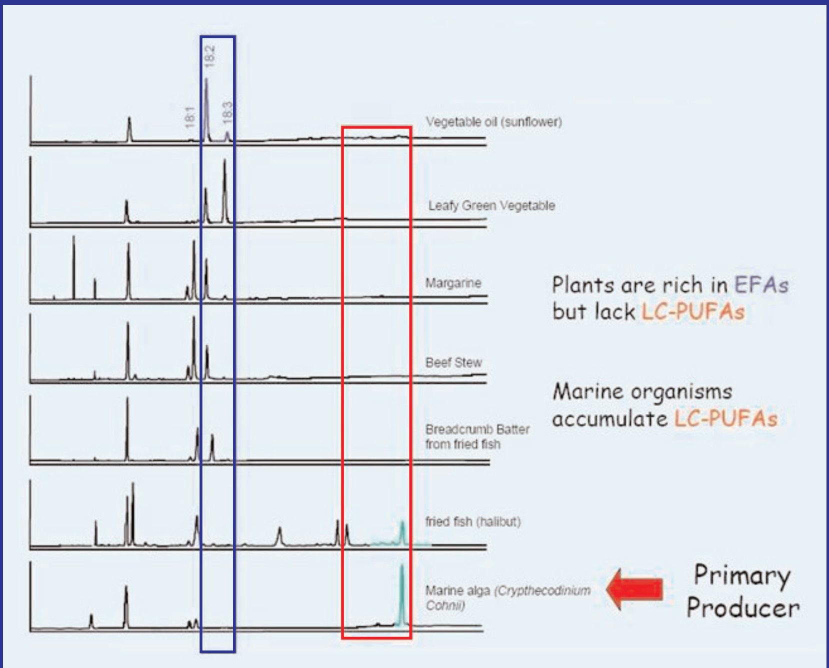
Table 1 (left) illustrates how fish and seafood are overwhelmingly the major source of LC omega-3 and that oily fish has an outstandingly high content.

Figure 2 (below) shows the distribution of different fatty acids in various foodstuffs. In the blue box are the Essential Fatty Acids (EFAs), ALA and LA, and in the red box are the long chain omega-3s. This figure shows that plants are rich in EFAs but lack LC omega-3s while fish and marine algae are rich in LC omega-3s.

Humans can achieve the UK target adult intake of 450mg/day by consuming two portions of fish per week, one of which is oily or by taking about three and half teaspoons of fish oil. While the target can also be achieved by eating foods fortified with omega-3s, it would, for example require consumption of 10 glasses of fortified milk per day or three cans of beans per day (ref. 13) to achieve the target intake.

The American Heart Association (AHA) is among the many organisations and experts which advise that EPA & DHA should be obtained "preferably from oily fish".

Figure 2.
The distribution of fatty acids in foodstuffs



Source: Napier (ref. 5.5)

Table 2.
Content of Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid (DHA) in various fish species

Type	DHA (g/100 g)	EPA (g/100 g)	DHA and EPA (g/100 g)	Ratio DHA:EPA
Tuna				
Bluefin	1.141	0.363	1.504	3.1:1.0
Light, canned in water	0.223	0.047	0.270	4.8:1.0
Albacore, canned in water	0.629	0.233	0.862	2.7:1.0
Anchovy	0.911	0.538	1.449	1.7:1.0
Salmon				
Atlantic, farmed	1.457	0.690	2.147	2.1:1.0
Atlantic, wild	1.429	0.411	1.840	3.5:1.0
Chinook	0.727	1.010	1.737	1.0:1.4
Sockeye	0.700	0.530	1.230	1.3:1.0
Mackerel, Atlantic	0.699	0.504	1.203	1.4:1.0
Menhaden*	1.19	1.84	3.03	1.0:1.54
Herring, Atlantic	1.105	0.909	2.014	1.2:1.0
Trout				
Rainbow, farmed	0.820	0.334	1.154	2.5:1.0
Rainbow, wild	0.520	0.468	0.988	1.1:1.0
Halibut	0.374	0.091	0.465	4.1:1.0
Cod	0.154	0.004	0.158	38.5:1.0
Haddock	0.162	0.076	0.238	2.1:1.0
Catfish				
Channel, farmed	0.128	0.049	0.177	2.6:1.0
Channel, wild	0.137	0.100	0.237	1.4:1.0
Swordfish	0.681	0.087	0.768	7.8:1.0
Grouper	0.213	0.035	0.248	6.1:1.0
Shrimp	0.144	0.171	0.315	1.0:1.2

*Figure assumes a body fat content of 14%

Source: ref. 2. Data from USDA Agricultural Research Service. Nutrient Data Laboratory. http://www.ars.usda.gov/nutrientdata. Accessed January 23, 2008.

SOURCES OF EPA & DHA FOR THE HUMAN DIET ARE:

1. Farmed fish and seafood fed on a diet including adequate levels of LC omega-3s, such as marine oils
2. LC omega-3 supplements – usually fish oil capsules
3. Meat, eggs or milk from animals whose feed is supplemented with adequate levels of LC omega-3s, such as marine oils
4. Enriched foods – where LC omega-3 is added during manufacture
5. Wild captured fish and seafood.
6. Meat, eggs or milk from animals whose diet is high in grass and certain other feeds available to free ranging animals.

For routes 1 to 4 above the source of LC omega-3 is usually natural fish oil from the processing of feed grade fish. Feed grade fish are predominantly oily fish which therefore have a high EPA & DHA content. Trimmings from food fish processing are also reduced to healthy fish oil and fishmeal – the latter usually being 6-10% oil.

Fish oil is used in human, farmed fish, pet and farm animal diets. Fishmeal is used in farmed fish, pet and farm animal diets where it provides both high quality natural nutrition and health and welfare benefits.

For several years there has been a move to replace fish oil and fishmeal in farmed carnivorous fish diets with vegetable alternatives for financial reasons. However recent work by Seierstad (ref.14) has shown that the fatty acid composition of the salmon meat affected the fatty acid profile of the patients' blood and that the advantageous marine omega-3 fatty acids (EPA & DHA) increased markedly in those patients that ate salmon fed on feed containing pure fish oils. It was also shown that in these patients the levels of marker substances for heart and vessel disease were much better than in patients eating salmon fed pure vegetable (rapeseed) oil or a mix of vegetable and fish oil.

TYPICAL RECOMMENDED ADULT INTAKES OF EPA & DHA

	g/day
• Typical recommended intake for those without heart disease	0.5
• Patients with known CAD	1.0
• Patients with hypertriglyceridemia	3.0 to 4.0

Both DHA and EPA should be consumed in roughly equal quantities

How much is 0.5g/day?

- 6 oz of salmon twice weekly
- 1 tablespoon of standard liquid fish oil taken twice weekly
- 1 to 2 capsules of standard over-the- counter fish oil per day

Omega-3 fatty acid supplements can be taken at anytime, in full or divided doses, without raising concerns for interactions with any medications. Omega-3 fatty acids persist in cell membranes for weeks after consumption, and thus intermittent bolus dosing, i.e. twice weekly intake of fish or fish oil, provides the same benefits as daily consumption of lower doses.

HEALTH AND WELFARE BENEFITS TO FARM ANIMALS AND PETS

It is not surprising, given all the health benefits for humans described in this datasheet, that there are also health benefits to animals from inclusion of EPA & DHA in their diets. While many animals such as chickens are better able to convert ALA to EPA & DHA than humans, they still seem to benefit from additional LC omega-3s. There are others like fish which have almost no ability to elongate and de-saturate ALA and as such must be fed adequate levels of EPA & DHA.

Where the animals are destined for human consumption there is the added advantage that an animal fed a diet rich in LC omega-3s will in turn make a useful contribution to the dietary intake of the final consumer. One of the most cost effective ways to ensure adequate levels of EPA & DHA is by including fishmeal in the diet of farmed fish and animals.

Fishmeal - used in the feed of farmed fish, pigs and poultry, and in pet food - typically contains between 6% and 10% fish oil by weight, but can range from 4% to 20%.

Modern intensive rearing systems put additional strain on an animal's immune system and there is evidence to support the view that the addition of fish oil either directly or from fishmeal can have a range of benefits. Animal welfare organisations also recognise welfare benefits to animals from LC omega-3s.

There is evidence of the following specific benefits from feeding fish oil and fishmeal (refs. 15 and 16):

SHEEP

- Decreased mortality in hill lambs and ewes
- Reduced losses in sheep challenged with worms

POULTRY

- Moderating over-reaction of the immune system and increasing specific immunity in poultry
- Reduction of performance loss due to coccidiosis in broiler chicks
- Resisting the challenge of ascites in broilers
- Reduced pecking among poultry
- Improved growth rates among broilers
- Reduced carcass condemnations in broilers
- More fertile cockerels

PIGS

- Reduced effects of sepsis (E.coli) in young pigs
- Reduced tail biting among pigs
- Higher numbers of piglets per litter

COWS, HORSES

- Improved fertility in the dairy cow
- Decreased risk of colic and laminitis in horses

PETS

A growing body of scientific research continues to show that omega-3 fatty acids benefit dogs and cats throughout the various stages of life including pregnancy, lactation, foetal development, growth and aging. The benefits extend to helping companion animals when they suffer from certain disease conditions.

Omega-3 fatty acids are essential for maintaining healthy organ systems and physiological functions. Deficiencies in omega-3 fatty acids may lead to a range of health problems, such as dry itchy skin, recurring skin and ear infections, autoimmune disorders, joint inflammation and arthritis, and loss of mental alertness and inactivity. Omega-3 fatty acids are recognised by veterinarians as important nutrients to incorporate in diets for daily consumption by companion animals.

Where producers of farmed livestock chose, or come under pressure, to decrease use of drugs including antimicrobials in feed - the preventative and protective qualities of adequate LC omega-3s become even more important.

CONCLUSION

The latest research is now clearly showing that our diets have changed over recent decades with increased intensive animal production and industrial food processing. Our intake of LC omega-3s has now fallen to levels where we are now recognising deleterious effects in the metabolism of a large percentage of the population. In order to correct this we need to increase our intake of LC omega-3 fatty acids as well as decrease our intake of omega-6 fatty acids.

This cannot be achieved just by the increased intake of the shorter chained omega-3 ALA because the rate at which this can be converted to EPA & DHA has been shown to be too slow to provide sufficient quantities. Increased ALA intake does have an advantage if it replaces omega-6 intake since the two are in competition for the same enzymes to produce longer chained fatty acids.

The best way to ensure an increased dietary intake of LC omega-3s is either by the direct increased consumption of wild caught sea food or the increased consumption of farmed fish or terrestrial animals fed a diet rich in LC omega-3s, such as chicken (meat and eggs) or pigs. The final way is by the intake of supplements such as fish oil capsules rich in EPA & DHA.

In their recent review paper on the importance of LC omega-3s Plorde and Cunnane conclude by stating: 'Returning to the key nutritional attributes of a shore-based diet, especially higher omega-3 and lower omega-6 LC fatty acid intake, is essential from a health perspective, or the consequences could be disastrous as much for mental as for cardiovascular health' (ref. 8).

MORE INFORMATION ON LC OMEGA-3S

1. **www.omega-3centre.com** – Information centre for Australia and New Zealand.
2. **www.goedomega3.com** - Global (Trade) Organisation for EPA & DHA.
3. **www.nutrition.org.uk** – British Nutrition Foundation.
4. **www.lipgene.ucd.ie** - Diet, genomics and the metabolic syndrome: an integrated nutrition, agro-food, social and economic analysis. Funded by the EU.
5. **www.dpag.ox.ac.uk** - Oxford University Department of Physiology, Anatomy and Genetics.
6. **www.americanheart.org**
7. **www.fin.org.uk**

REFERENCES

1 *M.A. Crawford and A.J. Sinclair.* Nutritional Influences in the Evolution of Mammalian brain in Lipids, *Malnutrition and the Developing Brain* Editors Elliot & Knight Elsevier 1972 267-292

2. *John H. Lee, MD; James H. O'Keefe, MD; Carl J. Lavie, MD; Roberto Marchioli, MD; and William S. Harris, Phd.* Omega-3 Fatty Acids for Cardioprotection - Mayo Clinic Proc. March 2008;83(3):324-332

3. *S. Allport.* The Queen of Fats: Why Omega-3s Were Removed from the Western Diet and What We Can Do to Replace Them," published February 8. 2008 University of California Press

4. *Wendy Morgan, Executive Director, Omega-3 Centre, Australia.* Omega-3 fatty acids – what are they and what do they do for you. IFFO Annual Conference, October 2007

5. Lipgene meeting – London, November 2007. LIPGENE (Contract FOOD-CT-2003-505944) is an EU Sixth Framework Integrated Programme being conducted by a consortium of 25 research centres across Europe. The project is entitled "Diet, genomics and the metabolic syndrome: an integrated nutrition, agro-food, social and economic analysis". It runs from 2004 to 2009

   5.1 *Christine Williams,* University of Reading , An introduction to Lipgene.

   5.2 *Joanne Lunn,* British Nutrition Foundation Omega-3 fatty acids – what they are and why we need them.

   5.3 *Rachael Gibbs,* University of Reading. Current intakes of omega-3 fatty acids in the UK and options for increase.

   5.4 *Douglas R. Tocher*, University of Stirling The issues surrounding fish as a source of long chain omega-3 fatty acids.

   5.5 *Jonathan Napier*. The production of long chain omega 3 polyunsaturated fatty acids in transgenic plants - towards a sustainable source of fish oils, Rothamsted Research.

6. *A. J. Richardson and P. Montgomery.* The Oxford-Durham study: a randomized controlled trial of dietary supplementation with fatty acids in children with developmental coordination disorder. (2005) Pediatrics 115 (5) 1360-1366.

7. *D. Mozaffarian and E. B. Rimm.* Fish intake, contaminants, and human health: evaluating the risks and the benefits, [Published correction appears in JAMA.2007 Feb 14; 297(6):590]. JAMA. 2006; 296(15):1885-1899.

8. *Mélanie Plourde, and Stephen C Cunnane.* Extremely limited synthesis of long chain polyunsaturates in adults: implications for their dietary essentiality and use as supplements. Applied Physiology, Nutrition, and Metabolism, Volume 32, Number 4, 1 August 2007, pp. 619-634(16) Publisher: NRC Research Press.

9. *P.L.Else and A.J. Hulbert.* Comparison of the Mammal Machine and the Reptile Machine: Energy Production, *American Journal of Physiology* 240 (1981) 3-9.

10. *L.H. Storlien et al.* Fish Oil Prevents Insulin Resistance Induced by High-Fat Feeding in Rats, Science 237 1987: 885-888.

11. *A. P. Simopoulos.* The importance of the ratio of omega-6/omega-3 essential fatty acids. Biomed Pharmacother. 2002 Oct;56(8):365-79.

12. *J. R. Hibbeln et al*. Healthy intakes of n-3 and n-6 fatty acids: estimations considering worldwide diversity. Am J Clin Nutr. 2006 Jun;83(6 Suppl):1483S–1493S.

13. *Professor Lesley Regan,* Imperial College. Personal communication.

14. *S. L.Seierstad et al.* Dietary intake of differently fed salmon; the influence on markers of human atherosclerosis. European Journal of Clinical Investigations (2005) 35:52-59.

15. *I. H. Pike,* Health benefits from feeding fish oil and fishmeal, IFOMA technical bulletin 28, May 1999.

16. *Gert J. Breur,* Co-Director, Omega-3 Learning and Education Consortium, Purdue University - Diet and health recommendations for dogs and cats.