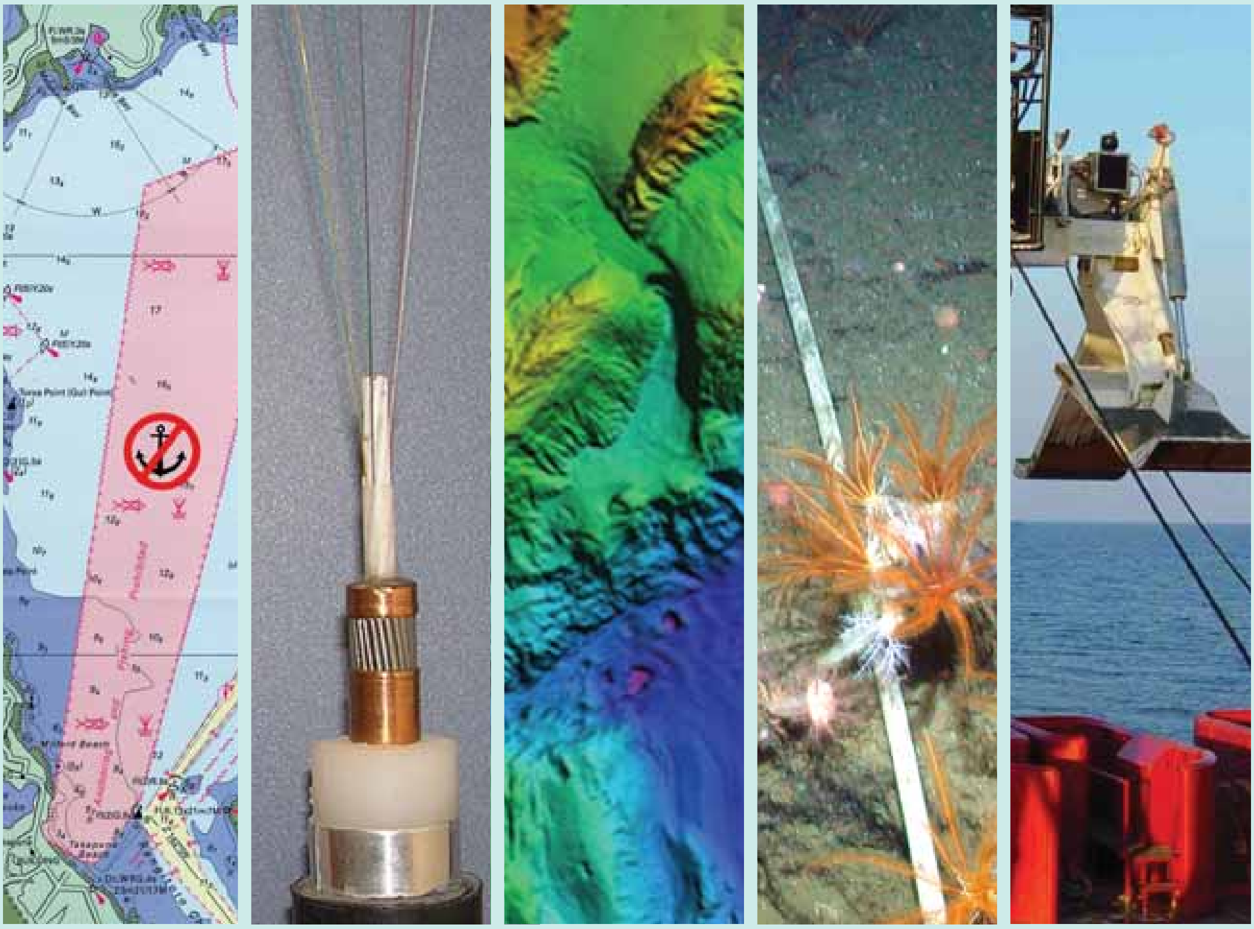
Submarine cables and the oceans: connecting the world



UNEP WCMC

International Cable Protection Committee

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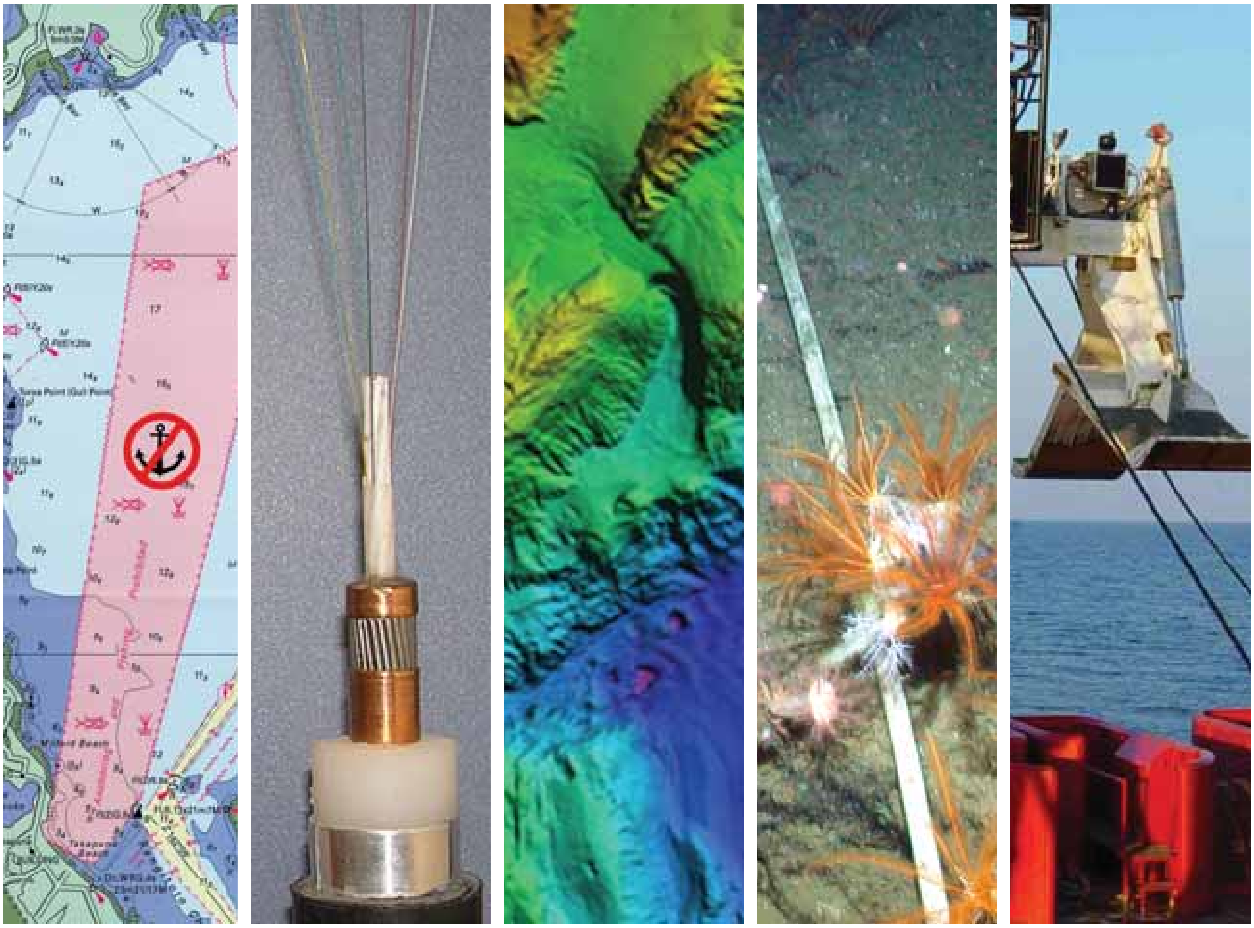

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The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) is the biodiversity assessment and biodiversity policy support arm of the United Nations Environment Programme (UNEP), the world's foremost intergovernmental environmental organization. The Centre has been in operation for over 25 years, combining scientific research with practical policy advice.

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DISCLAIMER

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The International Cable Protection Committee Ltd (ICPC) is a non-profit organization that facilitates the exchange of technical, legal and environmental information concerning submarine cable installation, maintenance and protection. It has over 100 members representing telecommunication and power companies, government agencies and scientific organizations from more than 50 countries, and encourages cooperation with other users of the seabed.

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Foreword

There are many things and services in our everyday life that we take for granted, and telecommunications is one of them. We surf the internet, send emails to friends and colleagues abroad, talk to family members in foreign countries over the phone, book airline seats and make banking transactions without actually realizing and appreciating the sophisticated technology that enables us to do so.

There is a common misconception that nowadays most international communications are routed via satellites, when in fact well over 95 per cent of this traffic is actually routed via submarine fibre-optic cables. Data and voice transfer via these cables is not only cheaper, but also much quicker than via satellite.

The first submarine cable – a copper-based telegraph cable – was laid across the Channel between the United Kingdom and France in 1850. Today, more than a million kilometres of state-of-the-art submarine fibre-optic cables span the oceans, connecting continents, islands and countries around the world. Arguably, the international submarine cable network provides one of the most important infrastructural foundations for the development of whole societies and nations within a truly global economy.

At the beginning of the submarine cable era, there was a widely held belief that the riches of the ocean were too vast ever to be affected by humans. Apart from shipping and regional fishing, there were few other uses of the sea and most of the marine environment (the little that was known) was still relatively pristine.

Today, the situation is vastly different. Human activities, directly or indirectly, have affected and altered all environments world-wide, including the 71 per cent of the planet that is ocean. The number and the intensity of maritime uses have increased dramatically and will continue to do so in the future, stretching the capacity of the oceans and their finite space and resources to the limit – or even beyond. In the light of the actual and potential pressures and impacts this creates on marine biodiversity and ecosystems (including the services and functions they provide for humankind and life on Earth), governments and international organizations have recognized that there is an urgent need for wise conservation and protection in concert with the sustainable management and use of the oceans and their resources. Even the placement and operation of submarine telecommunications cables, as one of the oldest and arguably one of the most important uses of the sea, has to be considered in this process. In order to focus and guide these deliberations and decision making, an objective, factual description of this industry and the interaction of submarine telecommunications cables with the marine environment is needed: information that the reader will find in this report.

We hope that this report will contribute to and strengthen the ongoing exchange of information, mutual education and cooperation between all stakeholders, so that, despite increasing technological change and environmental pressures, we can continue to share the seabed in harmony for the benefit of all.

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Contents

Acronyms and abbreviations

ACC	Antarctic Circumpolar Current
ACMA	Australian Communications and Media Authority
AT&T	American Telephone and Telegraph Company
ATOC	Acoustic Thermometry of Ocean Climate
CANTAT	Canadian Trans-Atlantic Telephone cable
CBD	Convention on Biological Diversity
CPZ	Cable protection zone
DTS	Desktop study
EEZ	Exclusive economic zone
EIA	Environmental impact assessment
ENSO	El Niño-Southern Oscillation
ESONET	European Seafloor Observatory Network
FAD	Fish aggregating devices
FAO	Food and Agriculture Organization of the United Nations
GCCS	Geneva Convention on the Continental Shelf
GCHS	Geneva Convention on the High Seas
GISS	Goddard Institute for Space Studies, NASA
GPS	Global positioning system
ICES	International Council for the Exploration of the Sea
ICPC	International Cable Protection Committee
IEEE	Institute of Electrical and Electronic Engineers, USA
IPCC	Intergovernmental Panel on Climate Change
ITLOS	International Tribunal for the Law of the Sea
MBARI	Monterey Bay Aquarium Research Institute, USA
NASA	National Aeronautics and Space Administration, USA
NEPTUNE	North-East Pacific Time-series Undersea Networked Experiments
NIWA	National Institute of Water and Atmospheric Research, New Zealand
NOAA	National Oceanic and Atmospheric Administration, USA
OFCC	Oregon Fishermen's Cable Committee
OOI	Ocean Observatories Initiative
OSPAR	Oslo and Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
ROV	Remotely operated vehicle
SCIG	Submarine Cable Improvement Group
TAT-1	Trans-Atlantic Telephone, first trans-ocean telephone cable
UKCPC	United Kingdom Cable Protection Committee
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UV-B	Ultra-violet light, type B
WCMC	World Conservation Monitoring Centre (of UNEP)

Introduction

This report results from collaboration between the United Nations Environment Programme (UNEP) and the International Cable Protection Committee (ICPC), which represents the majority of ocean users within the submarine telecommunications cable industry. Why is such a report required? The last 20 years have seen exponential growth of and increasing reliance on the internet for communication, commerce, finance, entertainment and education. That remarkable development has been accompanied by rapid growth in international telephone communications. Whether sending an email, making an airline booking or simply telephoning overseas, there is more than a 95 per cent probability that those actions will involve the international submarine cable network. In recognition of its importance as the backbone of the internet, governments now view the submarine telecommunications cable network as *critical infrastructure* that deserves a high level of protection (e.g. ACMA, 2007).

The communications revolution has occurred against a backdrop of greater pressure on the ocean from increased human activities, which range from the exploitation of resources to anthropogenic global warming (e.g., UNEP-WCMC, 2009; IPCC, 2007). In response to concerns about potential and actual impacts on the marine environment, governments and international organizations have stepped up their efforts to ensure the conservation, protection and sustainable management/use of coastal seas and deep offshore waters. In the light of recent scientific discoveries (e.g. Masson *et al.*, 2002; Freiwald *et al.*, 2004), discussions about the risks to vulnerable and threatened marine ecosystems and biodiversity in areas beyond national jurisdiction have emerged. It was this increased international awareness and interest in the deep and high seas environments that led UNEP and the ICPC to collaborate in the preparation of this report in 2004, with the shared objective of providing a factual context for discussions involving submarine fibre-optic cables and the environment. As such, it allows for more informed decision making, especially when weighing the benefit of an activity against any potential negative environmental impact (e.g. UNEP, 2007). It should be noted that *Submarine Cables and the Oceans – Connecting the World* focuses exclusively on fibre-optic telecommunications cables, and hence does not address submarine power cables.

The opening chapters of this report are a compendium of information that starts with a history of submarine telecommunications cables. The first trans-oceanic cable came into full operation in 1866, when a link was established between Ireland and Newfoundland that allowed transmission of seven words per minute via telegraph. Today, a modern fibre-optic cable can transport vast amounts of data and is capable of handling literally millions of simultaneous telephone calls. Even so, deep-ocean fibre-optic cables are no larger than 17–21 mm diameter – about the size of a domestic garden hose. Closer to shore (in water depths shallower than about 1,500 m), a cable's diameter may increase to 40–50 mm due to the addition of protective wire armouring. Chapter 3 focuses on submarine cable operations and presents an insight into the technology that permits accurate placement of a cable on or into the seabed. Modern seabed mapping systems such as multibeam side-scan sonar and high-definition seismic profilers, used in conjunction with satellite navigation equipment, permit submarine cables to be installed with unprecedented precision. Thus, hazardous zones and ecologically sensitive locations, such as volcanic areas and cold-water coral communities, can be avoided. All cables eventually come ashore, and it is in these shallow coastal waters that they are at most risk from human activities, especially ships' anchoring and bottom trawl fishing, which are together responsible for most submarine cable faults. As a result, special protective measures are needed that typically include the addition of steel armour to the cable exterior and, where possible, burial into the seabed. Cable deployment within the waters of a coastal state generally requires some form of environmental impact assessment (EIA) covering the potential effects of the survey and laying operations on the local environment, other seabed users and underwater cultural heritage sites.

The success and very existence of international submarine cable systems owe much to the treaties that the nations of the world have introduced into customary international law since 1884. These international norms are widely accepted and followed by the cable industry as well as the global community. They are an excellent example of international law working at its best in balancing competing uses in the ocean. Chapter 4 provides a basic restatement of the current international legal regime that underpins the world's undersea communications network.

Open-file information from environmental agencies, together with published studies, forms the basis of Chapter 5, which examines the environmental impacts of modern submarine cables and associated operations. The main threats to cables are found in water depths shallower than about 1,500 m, the present limit of most bottom trawl fishing, although some boats are extending that limit to 2,000 m depth. In these continental shelf and slope areas, cables require some form of protection. This may be achieved through legislation for the creation of protection zones (e.g. ACMA, 2007), or by physical means such as burial beneath the seabed. In the case of designated and controlled protection zones, there may be no need to bury cables, in which case they are exposed to waves, currents and the marine biota. How a cable interacts with the environment depends on the many influences and factors that shape the ocean. However, the small physical size of a telecommunications cable implies that its environmental footprint is likely to be small and local; a suggestion that is borne out by several studies, e.g. Kogan *et al.* (2006). Using a combination of sediment samples and direct observations made with a remotely operated vehicle (ROV), Kogan *et al.* concluded that a telecommunications cable off Monterey Bay, California, had minimal to no impact on the fauna living in or on the surrounding seabed, with the exception that the cable locally provided a firm substrate for some organisms that otherwise would not have grown on the mainly soft seafloor sediments. These results contrast with the findings of an earlier study by Heezen (1957), who documented a significant impact on marine life, namely the entanglement of whales with old telegraph cables. However, such distressing occurrences were restricted to the telegraph era (1850s to c.1950s). With improved design, laying and maintenance techniques, which developed with the first coaxial submarine cables in the 1950s and continued into the fibre-optic era beginning in the 1980s, no further entanglements with marine mammals have been recorded (Wood and Carter, 2008). The remainder of Chapter 5 considers the environmental effects of cable burial and recovery as well as broader issues concerning the relationship between cables and ecologically sensitive areas, and the potential use of cable protection zones as *de facto* marine sanctuaries.

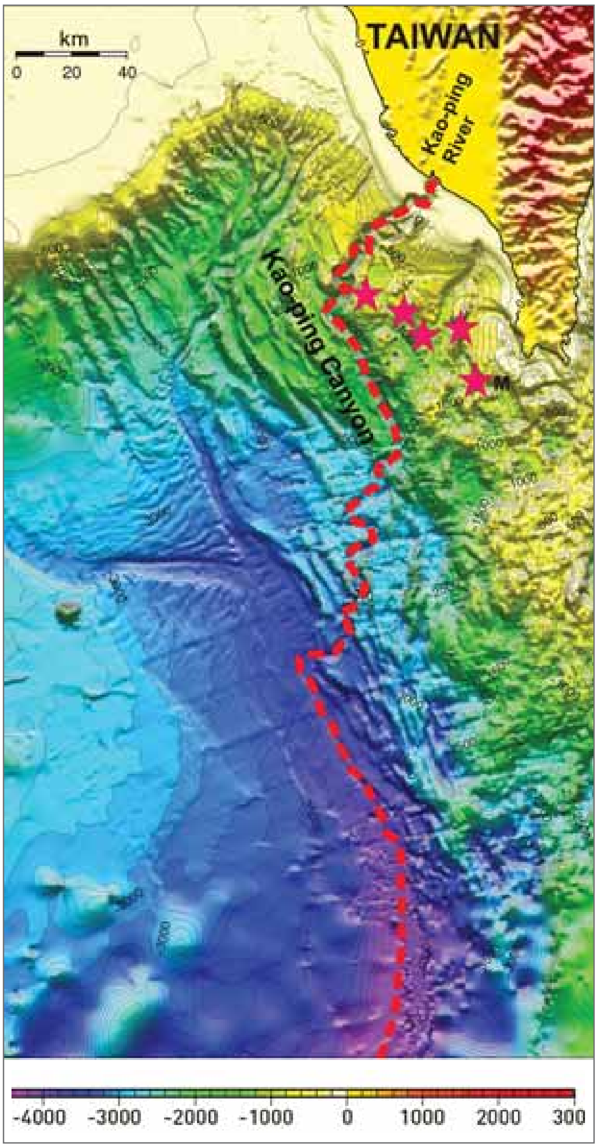


Figure 1: On 26 December 2006, a magnitude 7.0 earthquake and after shocks (pink stars) set off several submarine landslides off southern Taiwan. These slides transformed into fast-flowing mud-laden currents that sped down Kao-ping submarine canyon (red dashes) into a deep-ocean trench: a distance of over 300 km. Nine cables were broken en route, disrupting international communications for up to seven weeks. *Source: Professor C.S. Liu, Institute of Oceanography, National Taiwan University.*

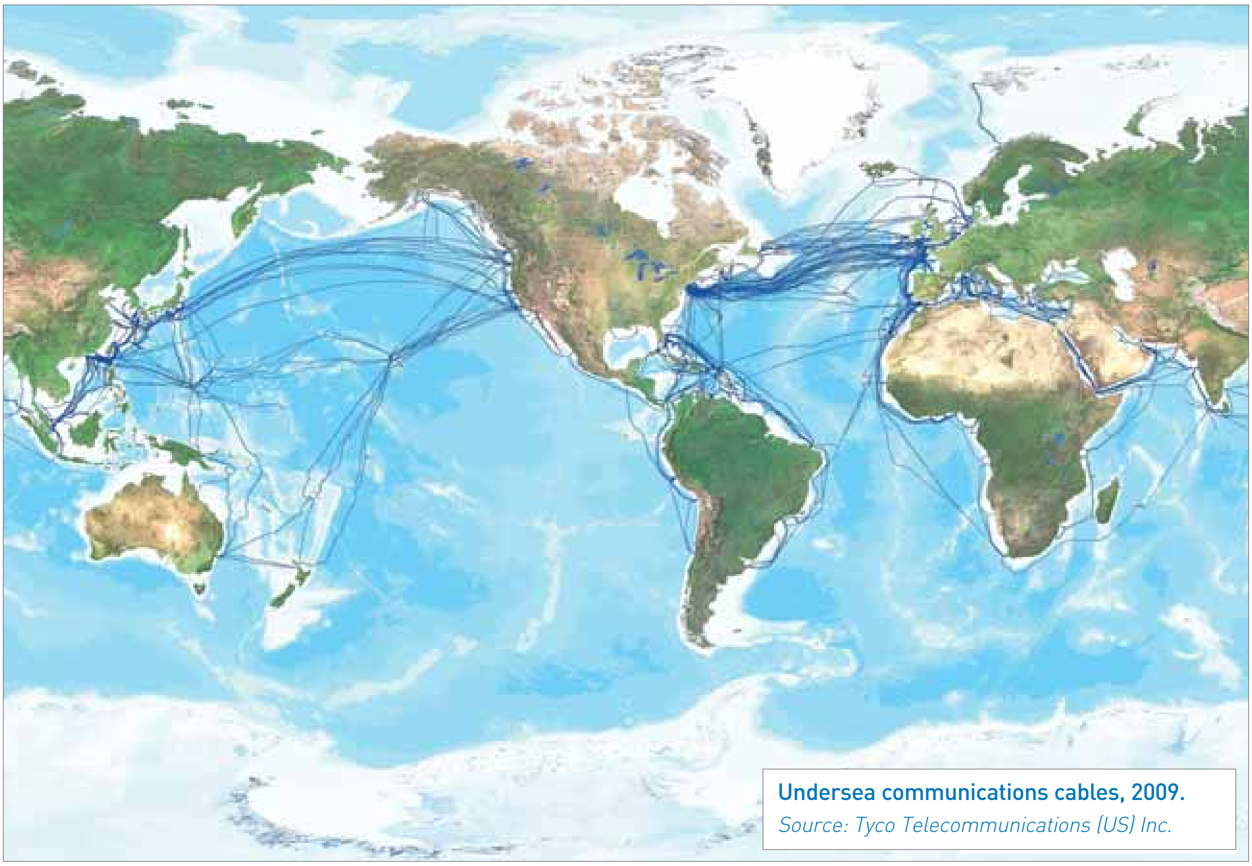
The December 2006 earthquake off southern Taiwan focused the world's attention not only on the human tragedy, but also on the impact of natural hazards on the submarine cable network. The magnitude 7.0 earthquake triggered submarine landslides and dense sediment-laden flows (turbidity currents), which passed rapidly down to the +4,000 m-deep ocean floor, breaking nine fibre-optic submarine cables en route (Figure 1). Southeast Asia's regional and global telecommunications links were severely disrupted, affecting telephone calls, the internet and data traffic related to commerce and the financial markets. As outlined in Chapter 6, such natural hazards generate less than 10 per cent of all cable faults, but fault occurrence rises to around 30 per cent for cables in water deeper than c.1,500 m, i.e. beyond the main zone of human offshore activities. And, as seen off Taiwan in 2006 and Newfoundland in 1929, the consequences of major hazards can be profound. Seismically triggered submarine landslides and turbidity currents, along with major storms, wave and current action, and even river floods, pose the largest natural threat to cables, with volcanic eruptions and iceberg scour playing very minor roles. Furthermore, cables are unlikely to be exempt from the anticipated changes in the ocean resulting from human-influenced climate change. High on the list of potential hazards are rising sea level and more powerful storms, which together are likely to threaten the shallow and coastal reaches of cable routes. Regional changes in wind patterns, precipitation and ocean currents are also likely to have an effect.

Integrating cable activities with other seabed uses is the theme of Chapter 7. Mid-water to bottom trawl fishing, dredging, ships' anchoring and some recreational activities threaten underwater communications. Because it is the most significant cause of cable faults, Chapter 7 concentrates on fishing, presenting an overview of fishing gear and practices, risks to cables, fishing vessels and crew, and means of reducing those risks. Risk reduction is achieved through close consultation between cable engineers and fishermen so that there is a full understanding of their respective equipment and operations, e.g. knowledge of the type of trawl gear deployed allows engineers to identify a suitable burial depth for a cable. Other mitigation measures may involve cable routing, armouring, clear identification of cable routes on marine charts, educational material and stakeholder working groups consisting of fishing and cable representatives.

The report ends with a discussion of future activities in the ocean based on present trends in offshore conservation, renewable energy development and resource exploitation. There is no doubt that the oceans, and especially the coastal seas, are under increasing pressure from a growing range of human activities. The past decade has witnessed an expansion of offshore renewable energy schemes (in particular wind turbine farms) as nations seek to lower emissions of greenhouse gases and establish secure supplies of energy. Fishing activities are changing due to reduced stocks in coastal seas. Trawling is now moving into deeper waters, although this may be tempered by the increased costs of operating further offshore, lower biomass in more distant, deeper waters and rapid stock depletion because of fish life-history characteristics (e.g. Clark *et al.*, 2000; Pauly *et al.*, 2003). As China, India and other nations develop their industrial sectors, the import of raw materials and export of manufactured goods have expanded. Shipping routes, traffic volumes and vessel size have all undergone major adjustments brought about by profound shifts in the global economy. Offshore exploration and production of hydrocarbons are also set to extend into deeper water, with operations taking place at depths of 3,000 m and beyond. Deep-sea mining for minerals has recently attracted increased interest, with commercial operations planned for the near future. Furthermore, the science community is establishing long-term ocean observatories (e.g. Ocean Sites, 2009) to determine how the deep ocean and seabed function, to discover what biodiversity and ecosystems they harbour, and to detect natural hazards and responses to climate change.

As a consequence of these pressures, nations and international groups are seeking to preserve ocean ecosystems through the formation of marine protected areas and similar devices (e.g. OSPAR Commission, 2009). In the face of increasing human activities in the marine environment, it has become vital for relevant parties and stakeholders to communicate and cooperate. In this manner, harmonious development and conservation of the 71 per cent of Earth's surface found beneath the oceans can be realized. This is far from an idle sentiment: it is founded on the extensive experience of the collaborators of *Submarine Cables and the Oceans – Connecting the World,* actively working with other seabed users.

1. A history of submarine cables



Undersea communications cables, 2009.
Source: Tyco Telecommunications (US) Inc.

TELEGRAPH ERA

Submarine cables were born around the 1820s. Baron Schilling von Canstatt, an attaché with the Russian Embassy in Munich, successfully exploded gunpowder mines using insulated wires laid across the River Neva, near St Petersburg (Ash *et al.*, 2000). His interest moved to the electric telegraph, which he integrated with another earlier device known as Schweigger's 'Multiplier', in order to improve the sensitivity of a compass needle. Once combined, 'Schilling's Telegraph' was able to communicate messages through a directed needle that moved across black and white paper disks representing letters of the alphabet and numbers (Stumpers, 1884; Ash *et al.*, 2000).

Inventions involving telegraphy escalated through the 19th century. In 1836, English chemist and inventor, Edward Davey, came close to completing a practical telegraph system. He envisioned an electric telegraph that could be insulated for protection and placed underwater with relay-type 'repeaters' to boost weak signals along the cable. This was the forerunner of the submarine telegraph cable. Close to success, Davey unexpectedly departed for Australia, leaving his main competitors, William Cooke and Charles Wheatstone, to complete an operational telegraph (Stumpers, 1884; Ash *et al.*, 2000). Their system was patented in 1837 and involved the identification of alphabetic letters by deflections of magnetic needles. At about the same time, Samuel Morse patented a telegraph based on an electromagnetic system that marked lines on a paper strip. The technique came into commercial reality in 1844 when a communications link was made between Baltimore and Washington, DC.

The concept of insulating submarine telegraph cables to make them durable, waterproof and sufficiently strong to withstand waves and currents, fostered several trials with different materials. In 1843, Samuel Morse produced a prototype by coating a hemp-covered cable in tar and pitch;

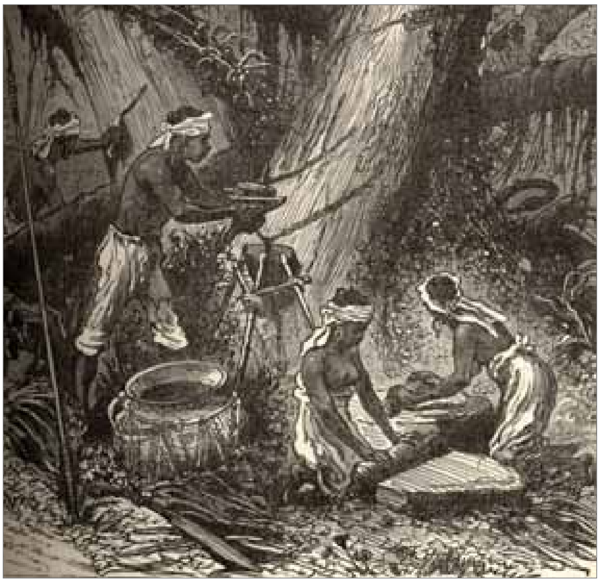


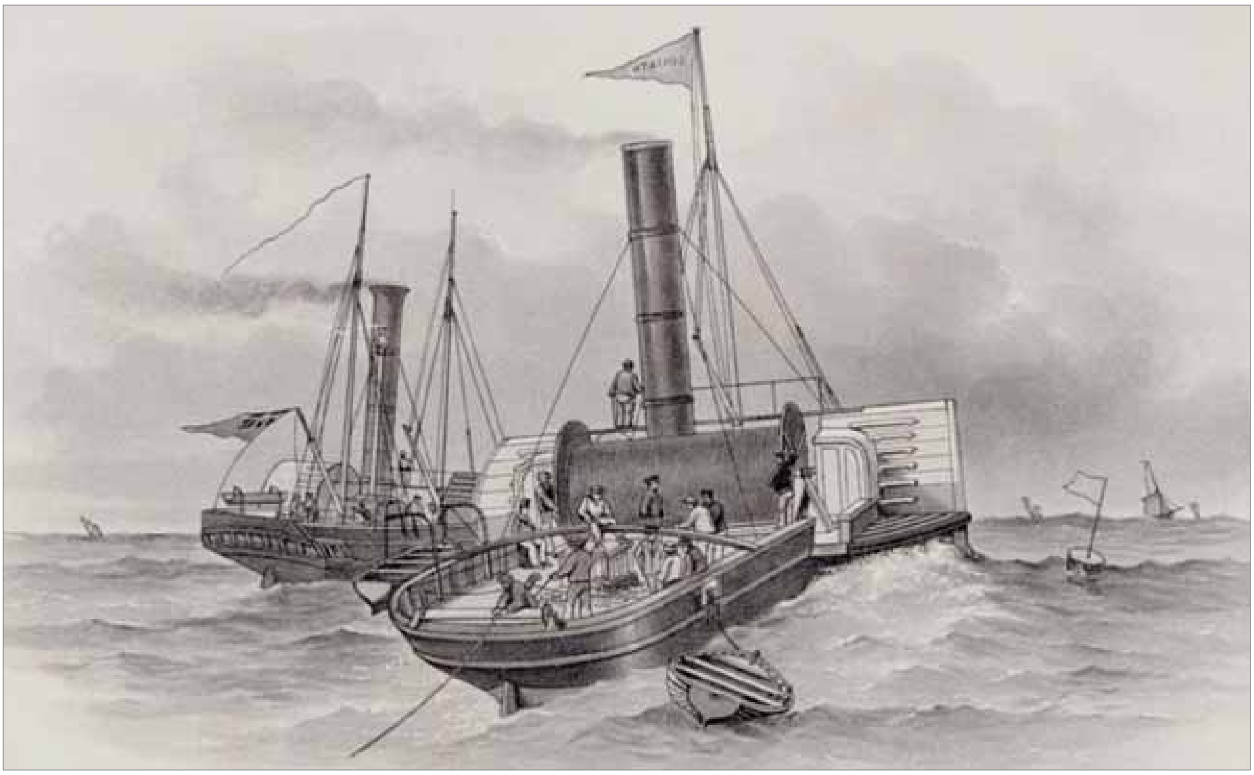
Figure 1.1: Tapping gutta percha, a natural polymer used for insulating early submarine cables. *Source: Bright (1898); courtesy of archives of BT Heritage.*

Figure 1.2: The steam tug, *Goliath*, laying the first international submarine cable between Dover and Calais, 28 August 1850. The vessel was accompanied by HMS *Widgeon*. *Source: Bright (1898).*

insulation provided by a layer of rubber also gave the cable strength and durability (Ash *et al.*, 2000). By the late 1840s, the basic technology existed to manufacture submarine cables, and in 1848 the Gutta Percha Company received its first order for wire insulated with a newly discovered natural polymer from Malaya – gutta percha (Figure 1.1) (Kimberlin, 1994; Gordon, 2002; ICPC, 2007).

An English merchant family, headed by the brothers James and John Brett, financed a submarine cable across the English Channel from Dover to Calais. Constructed from copper wire and gutta percha without any form of protection, the cable was laid by the tug *Goliath* on 28 August 1850 (Figure 1.2) (Kimberlin, 1994; Ash *et al.*, 2000; Gordon, 2002). The cable lasted for just a few messages before it succumbed to vigorous waves and currents. A year later it was replaced by a more robust design comprising four copper conductors, each double coated with gutta percha, bound with hemp and heavily armoured with iron wires. This improved version extended the cables' working life to a decade. After installation, John Brett sent a special message to soon-to-be Emperor of France, Napoleon III – an act that symbolically marked the day that submarine telecommunications became an industry. By 1852, cables also connected England to the Netherlands and Germany, with other links between Denmark and Sweden, Italy and Corsica, and Sardinia and Africa.

Submarine cables of that time were far from perfect.



The copper used for the conductors tended to be hard, brittle and poorly conductive, while the gutta percha insulation was sometimes lumpy and only moderately flexible. There was a need to improve cable design and materials as the emerging communications industry looked to the Atlantic Ocean as the next great challenge (Figure 1.3). Such a communications link would allow British and American businesses to develop trade – particularly the British cotton industry.

In 1854, Cyrus Field, a wealthy American paper merchant, became interested in laying a telegraph cable across the Atlantic Ocean (Gordon, 2002). Along with John Brett and Sir Charles Bright, he founded the Atlantic Telegraph Company in 1856 (Ash *et al.*, 2000). Its board members included William Thomson, the eminent physicist who later became Lord Kelvin. After an unsuccessful attempt in 1857, the company laid the first trans-Atlantic cable in 1858, when Ireland was linked to Newfoundland (Figure 1.4). However, success was short lived, and after 26 days of operation the cable failed. Following three other attempts, a new and improved cable was laid in 1866 from the *Great Eastern* cable ship by the Telegraph Construction & Maintenance Company (TELCON) – a merger of the Gutta Percha Company and Glass, Elliot & Company (Figure 1.5). The new and more durable cable provided reasonably reliable communication at around 12 words per minute across the Atlantic. On its return journey to England, the *Great Eastern* recovered the cable lost the year before. A repair was made and connection with Newfoundland completed to provide a second trans-Atlantic cable link (Ash *et al.*, 2000; Gordon, 2002).

As telegraph technology and laying techniques improved, the submarine network expanded greatly. To facilitate government and trade, cables linked the United Kingdom with the many outposts of its empire. By the early 20th century, much of the world was connected by a network that enabled rapid communication and dissemination of information for government, commerce and the public.

The durability and performance of telegraph cables improved with new conducting, strengthening and insulating materials. Alloy tapes and wires, such as the iron-nickel, permalloy, and the copper-iron-nickel, mu-metal, were used to increase cable performance (particularly the speed of signalling) in the 1920s. Staff employed to send and receive telegraphic messages at relay stations were gradually replaced by electro-mechanical signallers. Transmission speeds increased progressively, and by the late 1920s speeds exceeding 200 words per minute became the norm.

By the 1930s there were just two cable manufacturers in Britain, TELCON and Siemens Brothers. The Great Depression and competition from radio-based communications made business difficult. As a result, TELCON merged with the submarine communications cable section of Siemens Brothers to form Submarine Cables Limited. Despite the technological advances of the telegraph, the developing radio industry could do something that the telegraph could not – namely produce intercontinental voice communications. Marconi's company, Imperial, owned the patent to radio communication; it joined forces with the cable industry after they were encouraged to merge by the UK government. And so, in 1934, Cable & Wireless was born. The new partnership enabled even more rapid communications, which came into their own during the Second World War. Radio was used for communicating with troops,

Figure 1.3: Loading gutta percha insulated cable for the *Great Eastern* cable ship. *Source: courtesy of archives of BT Heritage.*

Figure 1.4: HMS *Agamemnon* laying the first Atlantic cable in 1858. *Source: ARC photographs from archives of BT Heritage.*

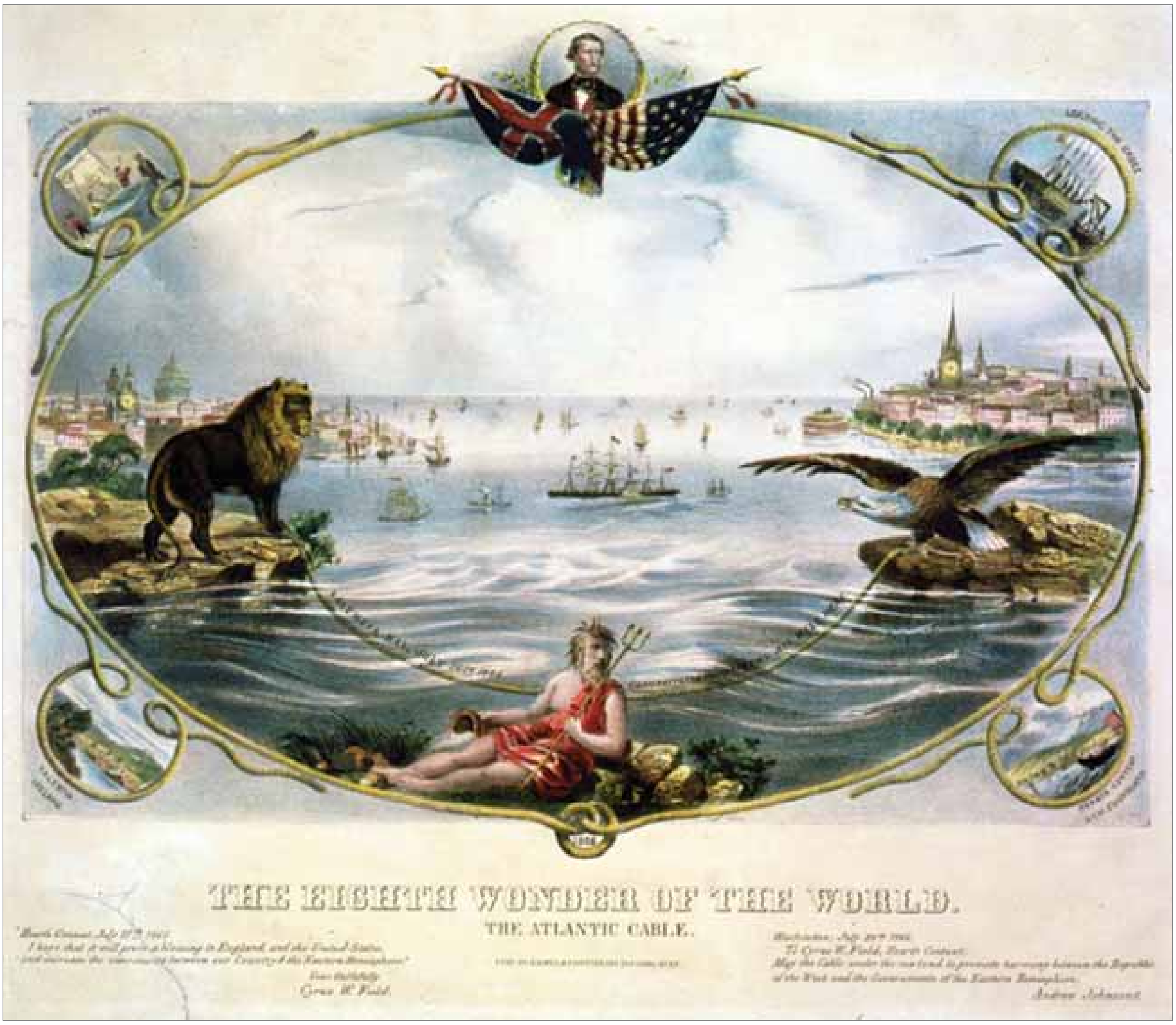


Figure 1.5: The first trans-Atlantic cables were promoted as the Eighth Wonder of the World by Cyrus Field and his colleagues, who emphasized cooperation between the United Kingdom and the United States. *Source: Kimmel and Foster (1866). Lithograph, Library of Congress.*

and submarine cables provided secure networks that could not be intercepted easily.

TELEPHONIC ERA

Following Alexander Graham Bell's invention of the telephone in 1875, it was only a matter of time before phone lines linked continents by submarine cables. Initial attempts in the United States and United Kingdom met with limited success. The British Post Office laid a telephone cable across the English Channel, but inherent deficiencies of the gutta percha insulation meant that signals were limited to short distances before they became distorted. The discovery of polyethylene in 1933 made trans-oceanic telephony possible. In 1938, a polyethylene-encased cable was developed with a copper coaxial core capable of carrying a number of voice channels (Chapter 2). That innovation, along with the use of repeaters to boost the signals, meant that a trans-oceanic cable with multiple voice channels was achievable. Thus in 1955–1956, two cables were laid between Scotland and Newfoundland as a joint venture between the British Post Office, American Telephone and Telegraph (AT&T) and the Canadian Overseas Telecommunications Corporation. The system, named TAT-1, came into service on 25 September 1956, and in the first day of operation carried 707 calls between London and North America. The era of submarine coaxial telephone communications had begun. With it came a suite of technological developments relating to the design of signal-boosting repeaters, new methods of

cable laying and improved methods of strengthening cables, especially in deep water where as much as 6 km of cable could be suspended through the water as it was laid on the ocean floor from a cable ship.

In the 1970s and early 1980s, these relatively low-bandwidth cables were only cost-effective on high-density communication routes, with the bulk of global trans-oceanic traffic carried by satellites. The last coaxial system across the Atlantic Ocean was TAT-7, which had a capacity of 4,000 telephone channels. However, to achieve this repeaters had to be installed at 9 km intervals, which made the technology very expensive. A more cost-effective solution was needed to meet the increasing demand for more capacity at reasonable cost. The race to develop fibre-optic technology for application in submarine cables began in the mid-1970s, thus heralding the dawn of another technological revolution in submarine communications.

Figure 1.6: CS *Long Lines* which, together with cable ships from France and the United Kingdom, laid the first trans-Atlantic fibre-optic cable (TAT-8). *Source: AT&T Inc.*

FIBRE-OPTIC ERA

Glass fibres could carry 12,000 channels, compared to 5,500 for the most advanced coaxial cable. Furthermore, the quality of fibre-optic communication was superior. However, at this stage it was difficult to envisage that fibre-optic cables would form a global network. Over the next decade, scientists continued to improve and refine fibre-optic technology. The world's first trial of a submarine fibre-optic cable was in Loch Fyne in 1979 (Ash *et al.*, 2000). The trials proved that the cable could withstand the mechanical stresses involved in laying, as well as retaining the required stability of transmission characteristics. By 1986, the first international system was installed across the

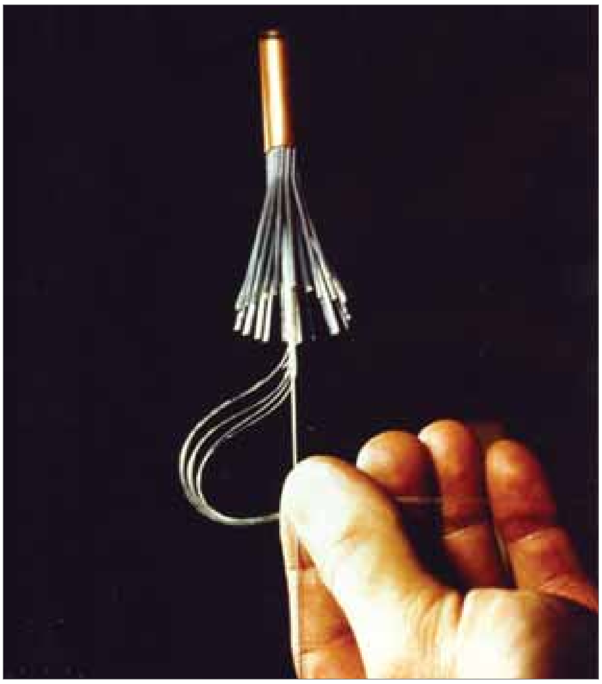


Figure 1.7: A section of TAT-8, the first trans-oceanic fibre-optic cable which, together with a developing internet, heralded a new age of communications. *Source: AT&T Inc.*

English Channel to link the United Kingdom and Belgium. In 1988, the first trans-oceanic fibre-optic cable was installed, which marked the transition when submarine cables started to outperform satellites in terms of the volume, speed and economics of data and voice communications. TAT-8 linked the United States, United Kingdom and France and allowed for a large increase in capacity (Figures 1.6 and 1.7). At about that time, the internet began to take shape. As newer and higher-capacity cable systems evolved, they had large bandwidth at sufficiently low cost to provide the necessary economic base to allow the internet to grow. In essence, the two technologies complemented each other perfectly: cables carried large volumes of voice and data traffic with speed and security; the internet made that data and information accessible and usable for a multitude of purposes. As a result, communications, business, commerce, education and entertainment underwent radical change.

Despite the success of submarine telecommunications, satellite transmission remains a necessary adjunct. Satellites provide global broadcasts and communications for sparsely populated regions not served by cables. They also form a strategic back-up for disaster-prone regions. By comparison, submarine cables securely and consistently deliver very high-capacity communications between population centres. Such links are also cost-effective, and the advantages of low cost and high bandwidth are becoming attractive to governments with low population densities. The amount of modern submarine fibre-optic cables laid in the world's oceans has exceeded a million kilometres and underpins the international internet. Almost all trans-oceanic telecommunications are now routed via the submarine cable network instead of satellite.

2. Inside submarine cables

DESIGNED FOR THE DEEP

A submarine cable is designed to protect its information-carrying parts from water, pressure, waves, currents and other natural forces that affect the seabed and over-lying waters. Most of these forces change with depth. Temperatures become colder, pressure increases and wave effects lessen, but strong current action can occur at any depth. There are also the impacts of human activities, most notably fishing and shipping.

Designing cables to meet such challenges has been a quest for more than 160 years. In 1842, for instance, a telegraph cable laid across the East River, New York, by Samuel Morse, was soon damaged by a ship's anchor. Designing cables to cope with such mishaps progressed rapidly. Redesigning the first cables across the English Channel in 1851 and the first trans-Atlantic link in 1858 allowed these pioneering systems, which had failed on their first deployments, to operate successfully (Chapter 1). Nevertheless, the fundamental design of telegraph cables changed little for the next 100 years (Figure 2.1; Haigh, 1968).

Telegraphy involved the transmission of coded electrical impulses through a conductor, which in a submarine cable was a stranded copper wire with gutta percha insulation wrapped in brass or jute tape (Figure 2.1). This construction, however, had insufficient strength to withstand deployment or recovery from any appreciable water depth. As a result, a sheathing of wires or *armour* was added to provide strength. Armour also protected the cable, and various wire types and layers were devised to meet different seabed conditions. Two-layered or double armour helped protect against anchors and fishing gear, as well as abrasion under wave and current action in coastal seas. Heavy single-armoured cable was designed

Figure 2.1: Submarine telegraph cables from the early 1900s, with the inner copper conductor for transmitting messages, an insulating layer of the tree resin, gutta percha, and one or more outer layers of iron wire for strengthening and protecting the whole assembly. *Source: Lonnie Hagadorn.*

Figure 2.2: Cables of the coaxial telephonic era, with a core of steel wires for strength, an inner copper sheath, which also acted as the conductor, encased in polyethylene dielectric, and an outer conductor. The assembly was coated with black polyethylene which, in shallow water, was armoured for protection. *Source: Lonnie Hagadorn.*

for intermediate water depths beyond the reach of anchors and most trawl fishing gear. Light single armour was a deep-water design that allowed cables to be laid in full ocean depths (Haigh, 1968).

ANALOGUE CABLES ARRIVE

Coaxial or analogue cables came into use in the 1950s and continued for the next 40 years and more. They differed from telegraph cables in three key ways:

1. Instead of gutta percha, polyethylene was used exclusively as the insulator or dielectric. It also formed the outer sheath of deep-ocean designs (Figure 2.2).
2. The cable core had a coaxial structure consisting of an inner and outer conductor of copper separated by polyethylene insulation material.
3. The first trans-Atlantic analogue cable (TAT-1) used traditional armour for strength. However, later cables used fine-stranded, high tensile strength steel wires encased in the central conductor. As a result, deep-ocean systems did not require armour, although cables in shallow seas still needed a strong outer casing for protection (Figure 2.2).

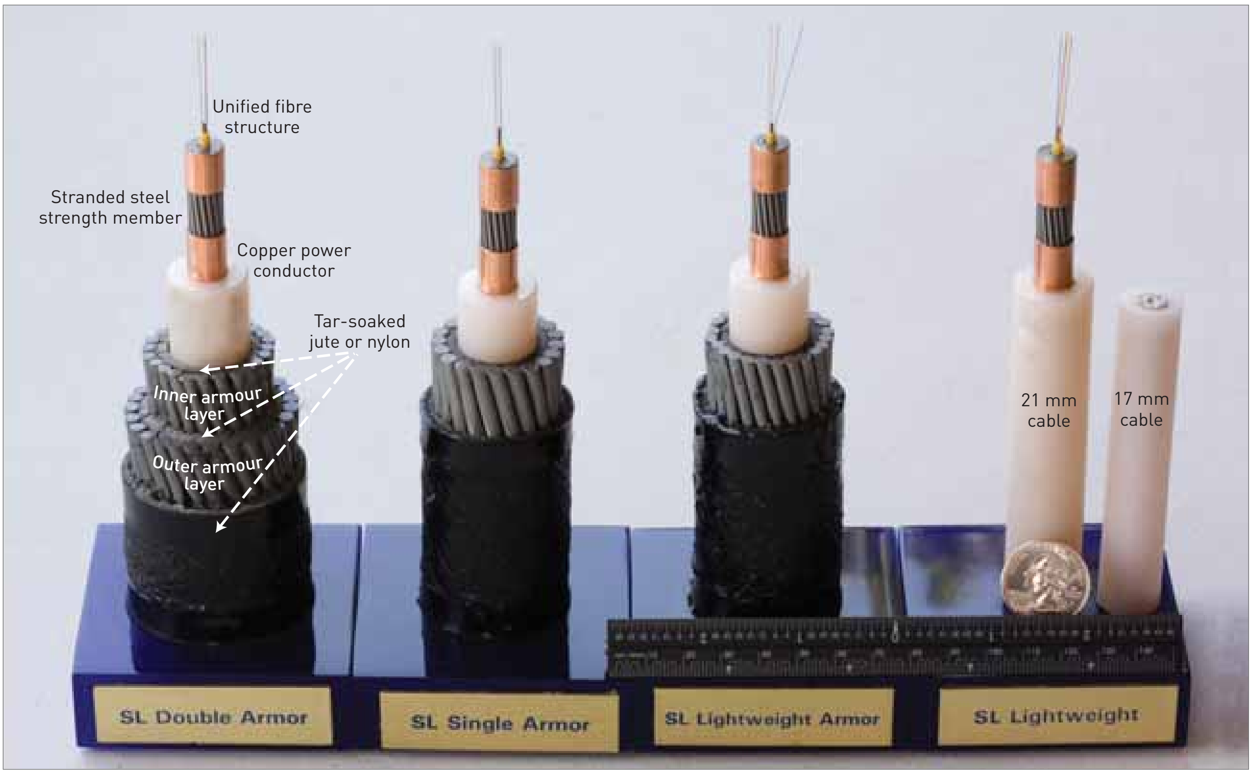
TAT-1 had about 36 individual voice channels, and used two cables, one for each direction of transmission. In addition, electrically powered amplifiers or repeaters were needed to boost the transmission, and these were inserted into the cable at spacings of c.68 km in deep water (Bell, 1957).

Analogue cable and repeater technology improved rapidly through the 1960s and 1970s, allowing a cable to carry up to 5,000 telephone calls. However, this increase in bandwidth was accompanied by an increase in cable size and repeater numbers, whose spacing was reduced to 6–9 km in the highest capacity systems. This made it extremely expensive to install trans-oceanic communication systems (Bell, 1957, 1964, 1970, 1978).

THE DIGITAL LIGHT-WAVE REVOLUTION

During the late 1970s and early 1980s, development focused on fibre-optic submarine cables that relied on a special property of pure glass fibres, namely to transmit light by internal reflection. By coding information as light pulses, data could be sent rapidly around the world. In 1985, the first deep-water repeatered design was laid off the Canary Islands. By 1988, the first trans-Atlantic fibre-optic cable (TAT-8) had been installed, followed several months later by

Figure 2.3: Shallow- to deep-water (left to right) fibre-optic cables, with a core supporting pairs of hair-like optical fibres surrounded by a layer of wire to provide strength, a copper conductor to power the repeaters or amplifiers that process the light signal, and a case of polyethylene dielectric. Wire armour is added for protection. *Source: Lonnie Hagadorn.*



the first trans-Pacific system. Such cables usually had two or more pairs of glass fibres. Originally, a pair could transmit three to four times more than the most modern analogue system. Today, a cable with multiple fibre-optic pairs has the capacity for over 1 million telephone calls. Despite this greatly enhanced capacity, modern cables are actually much smaller than analogue predecessors. Deep-ocean types are about the size of a garden hose (17–20 mm diameter), and shallow-water armoured varieties can reach up to 50 mm diameter (Figures 2.3 and 2.4). This means that instead of making four or five ship voyages to load and lay an analogue cable across the Atlantic, only one or two voyages are now required for fibre-optic types. It also means that the footprint of the cable on the seabed is reduced (AT&T, 1995).

Modern repeaters

With the digital light-wave revolution came major changes in the design of repeaters (Figure 2.5). Light signals still required amplification, and initially electronic regenerators were placed along a cable to boost signals. New systems, however, rely on optical amplifiers – glass strands containing the element erbium. Strands are spliced at intervals along a cable and then energized by lasers that cause the erbium-doped fibres to 'lase' and amplify optical signals. The typical spacing for this type of repeater is 70 km.

Fibre design changes

Since the advent of fibre-optic systems, major advances have been made in the manufacturing technology of the actual fibres. Various impurities or *dopants* are now added or removed from the glass to change its light-transmitting properties. The result is that the speed at which light passes along a glass fibre can be adjusted and controlled. This allows customized cables to be built to meet the specific traffic and engineering requirements of a route. This specialist use has increased the need for specialized repair services. The correct spare cable and fibre type must be used, which means that a comprehensive stock has to be carried by the cable repair authority. Repairs typically require removal of the damaged section followed by the splicing or jointing of the replacement section. During the telegraph and analogue eras, a single repair joint was a relatively quick (3–6 hours) and simple operation. It has now become a lengthy (10–24 hour), very specialized task that requires expensive and sensitive equipment. Hair-thin optical fibres must be aligned and spliced perfectly, followed by full testing before making the mechanical joint to give the repair strength and protection (AT&T, 1995).

CONCLUSIONS

The progress made in submarine cable design over the last 50-plus years has been remarkable. The world has

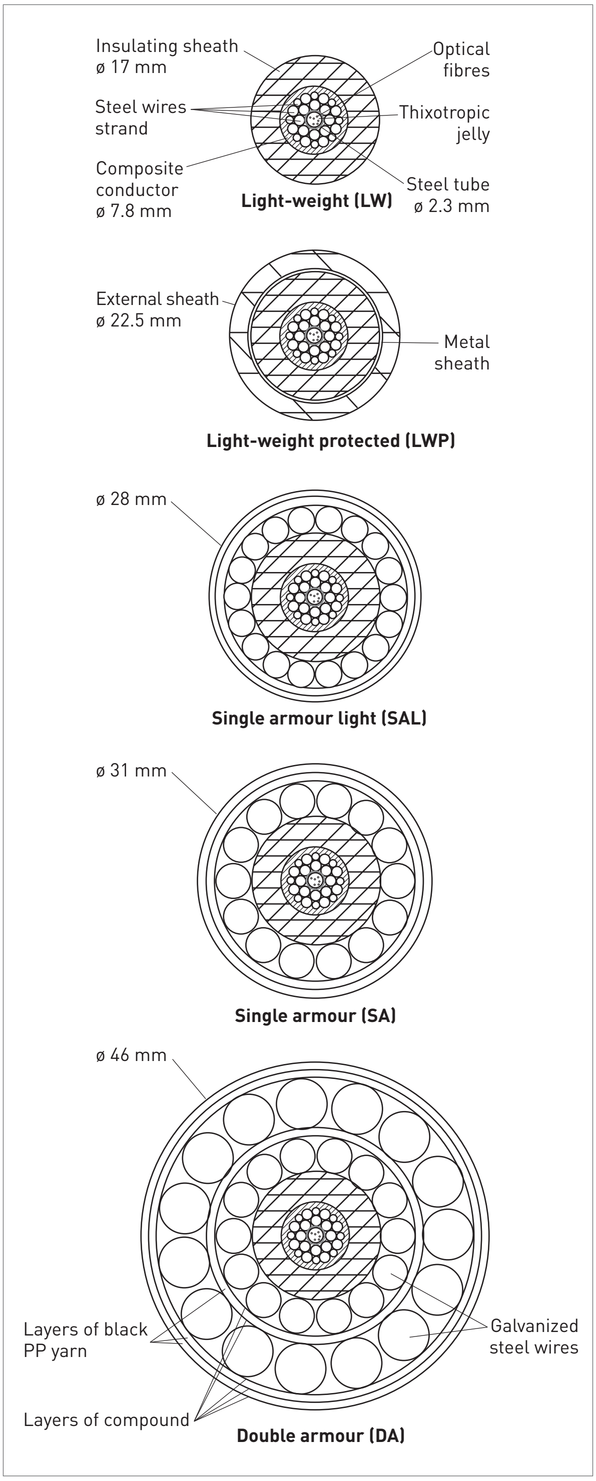


Figure 2.4: Modern fibre-optic cables (life-size), ranging from the typically used deep-ocean types (top two) leading to the shallow-water armoured varieties, which in many instances are now laid and buried into the seabed for additional protection. *Source: Lonnie Hagadorn.*

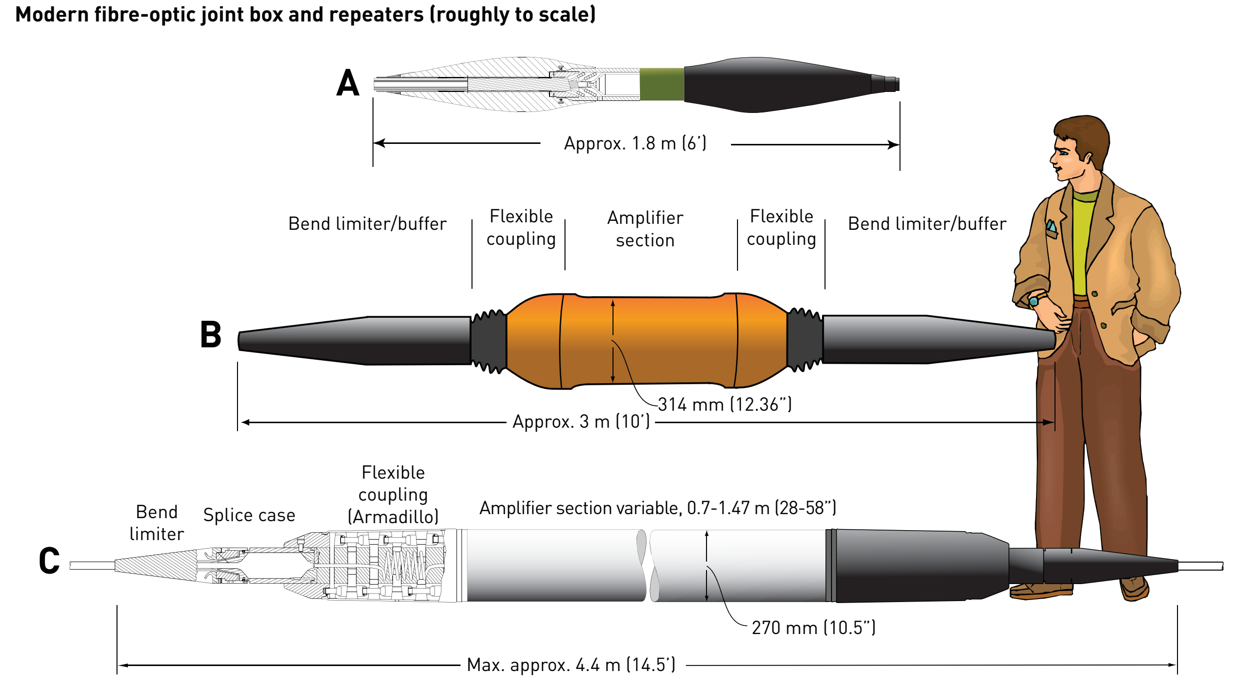


Figure 2.5: Representative repeaters from different manufacturers. The housings can accommodate as many as eight individual regenerators, or more recently, optical amplifiers. *Source: Lonnie Hagadorn.*

gone from single-circuit telegraph cables to fibre-optic systems with almost unlimited voice and data carrying capacities. The physical size of the cable itself has shrunk dramatically, and the reliability of the submarine components is down to just a few failures over the entire life of a long-distance system, which is typically 15–20 years. One can only wonder what progress the next 50 years will bring!

3. Survey, lay and maintain cables

ROUTE SELECTION

A key part of route selection is the identification and understanding of marine geopolitical boundaries that a proposed route may encounter. Access to databases such as Global Maritime Boundaries (NASA, 2009) can prevent unnecessary passage through areas where geopolitical constraints could affect the application or permit to place and maintain a cable on the seabed.

Definition of these maritime boundaries is provided by the United Nations Convention on the Law of the Sea (UNCLOS) (Chapter 4). The extent to which any coastal state controls cable-related activities within its territorial seas and exclusive economic zone varies, and depends on the nature and geographical jurisdiction of federal, state and/or local regulations that enact the provisions of UNCLOS in domestic legislation. For countries that have not ratified UNCLOS, the focus is on existing domestic legislation.

ROUTE SURVEY

Following the identification of potential cable landings that are to be connected, it is most effective to conduct a full review of pertinent available information in order to define the most efficient and secure route that will then be fully surveyed. This preliminary engineering, commonly referred to as a desktop study (DTS), is generally conducted by marine geologists with cable engineering experience who assemble all available hydrographic and geologic information about the pertinent region, commission fisheries and permitting reports if appropriate, consider the location and history of existing nearby cables and other obstructions, and then design an optimal route to be surveyed. The DTS will also generally include visits to the landings to determine where the cable crosses the beach and links to the cable terminal. Visiting landing sites also provides an opportunity to consult with local officials about possible cable hazards, environmentally sensitive areas, requirements to gain a permit to operate, fisheries, development plans and land access, amongst other factors. A comprehensive DTS will provide an optimal route design that can then be surveyed in the most cost-effective manner.

Based on the DTS, an efficient survey can then be designed along an optimized route to fully characterize that route and to avoid hazards and/or environmentally significant zones that may not have been identified from existing information. Surveys include water depth and seabed topography, sediment type and thickness, marine faunal/floral communities, and potential natural or human-made hazards. Where appropriate, measurements of currents, tides and waves may be needed to evaluate the stability of the seabed, movement of sediment and ocean conditions that may affect cable-laying and maintenance operations.

A route survey commonly covers a swath of seabed c.1 km wide in water depths down to about 1,500 m, reflecting the need to bury cables for protection according to local conditions. The width of the survey corridor can be adjusted largely in consideration of the expected complexity of the seabed, and the depth to which these complete surveys are conducted will be based on local hazards, particularly bottom trawl fishing and shipping activities, which may require the cable to be buried. Water depth is traditionally measured by echo-sounding, which has now developed into seabed mapping or *multibeam* systems. Whereas conventional echo-sounders measure a single profile of water depth directly under the ship, multibeam systems provide full depth coverage of a swath of seabed with a width that is three to five times the water depth (Figure 3.1). Thus, in deep water, a single multibeam track can be up to 20 km wide. As a result, sectors of the seabed are fully covered by a dense network of depth soundings that yield highly accurate images and charts (Figure 3.2).

As multibeam data are collected, side-scan sonar systems may be deployed to produce photographic-like images of the seabed surface. Termed *sonographs*, the images are used to identify zones of rock, gravel and sand, structures such as sand waves, and human-made objects ranging from shipwrecks to other cables. These images, together with multibeam data and seabed photography, have also been used successfully to map benthic habitats and communities (e.g. Pickrill and Todd, 2003). If cable burial is required, seismic sub-bottom profilers are deployed to measure the type and thickness of sediment below the seabed as well as possible natural hazards (Chapter 6). Like echo-sounders, the seismic profilers direct acoustic energy from the ship to the seabed. However, instead of just echoing off the seabed surface, the energy also penetrates through the substrate and reflects off layers of sediment to produce records of their thickness and structure. Sediment coring and other geotechnical testing of the seabed are also generally conducted to help determine its stability and suitability for cable burial.

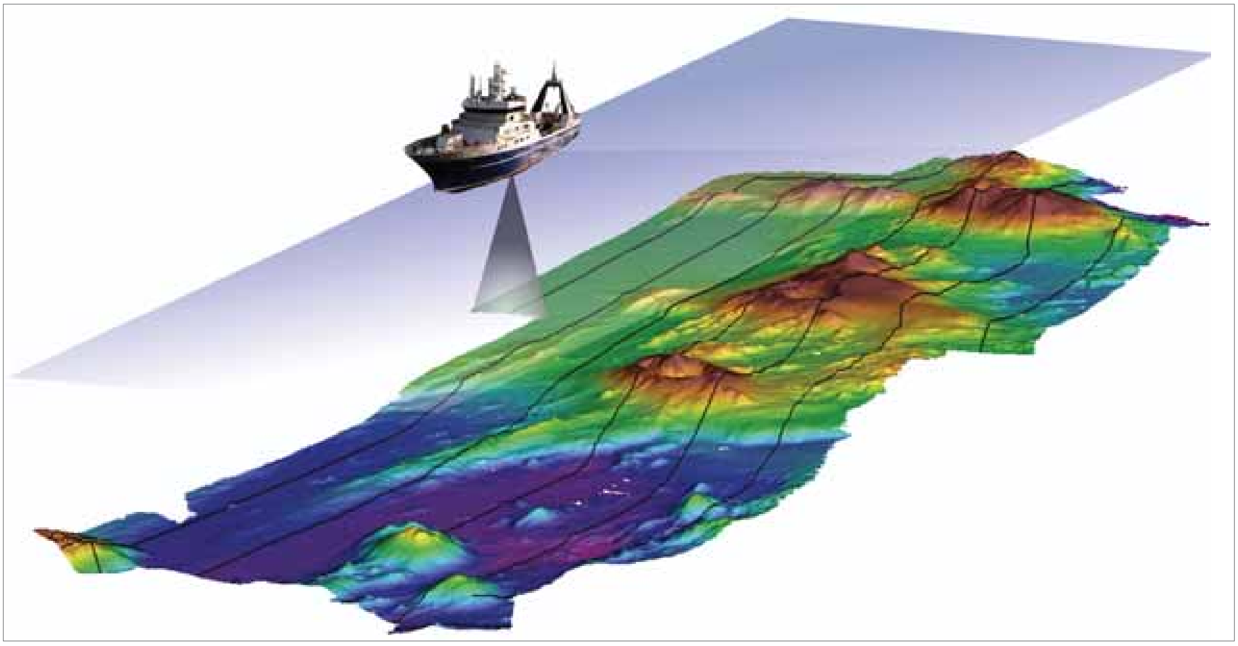


Figure 3.1: 'Mowing the lawn': a survey ship, equipped with a multibeam mapping system and guided by satellite navigation, charts the seabed to provide total coverage with depth soundings along a swath of seabed that can be 20 km wide. *Source: NIWA.*

For depths where burial is not required, a single track of a vessel using multibeam bathymetry will generally suffice. The data acquired during such surveys are constantly monitored so that if an unexpected hazard, cable obstruction or benthic community is identified, the surveyors can immediately adjust the planned route and detour around any hazardous or ecologically sensitive areas.

Ultimately, the desktop and field surveys will define a viable cable route and identify the natural and human activities that could impinge on the cable. This information guides the cable design so that it meets the specific conditions of the route.

CABLE DEPLOYMENT

As a cable enters the water, its path to the bottom is affected by the marine conditions and any variation in the operations of the laying vessel (Roden *et al.*, 1964). These can be distilled into three key parameters, which are: the ship's speed over the ground, the speed of the cable as *payed out* from the cable ship, and water depth (other less important factors are not covered here). Initially, a cable must be payed out slowly, with the vessel moving 'slow ahead' until the cable reaches the seabed. This is the *touch-down point*. Then the ship can increase its laying speed up to a practical maximum of about 11–15 km/hr (6–8 knots), periodically slowing down to pass repeaters or amplifiers through the cable-handling machinery that controls cable tension and pay-out speed. Once a steady state is achieved, the cable pay-out speed should approximate ship's speed plus 2–3 per cent, assuming the seabed topography is fairly constant. In this steady state, the catenary of the cable will be minimized in the water column. Laying up-slope, however, requires the pay-out speed to be less than the ship's speed because the water becomes shallower. The opposite is true when laying down-slope, because as water depth increases, more cable is needed to

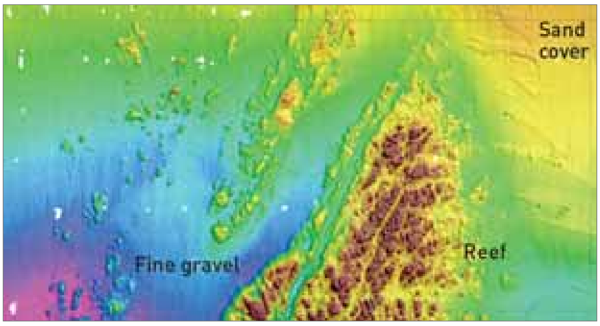


Figure 3.2: A detailed multibeam image of a rocky reef, fractured by faults and joints, and surrounded by a zone of fine gravel that is overlain by a 1 m-thick layer of mobile sand. Ideally, a cable would be buried below the sand and gravel along a route designed to avoid the rocky reef. *Source: NIWA.*

reach the seabed at the engineered touch-down point, assuming the ship's speed remains constant.

Laying operations on a modern vessel undergo constant and accurate monitoring. The ship's position and speed over the ground are measured by the satellite-based differential global positioning system, and the water depth by precision echo-sounders and seabed mapping systems (see *Route survey*), whereas cable pay-out speed and length are recorded by a *rotometer*. Onboard, the cable engineer scrutinizes laying progress with constant reference to the engineered route plan, making adjustments if necessary. In addition, there may be computerized tracking of the entire laying operation that includes detection of external factors such as winds and ocean currents, plus the means to correct for such influences.

Once laid, the cable comes ashore and is connected to the terminal or cable station, which assumes full management of the telecommunications system (Figure 3.3).

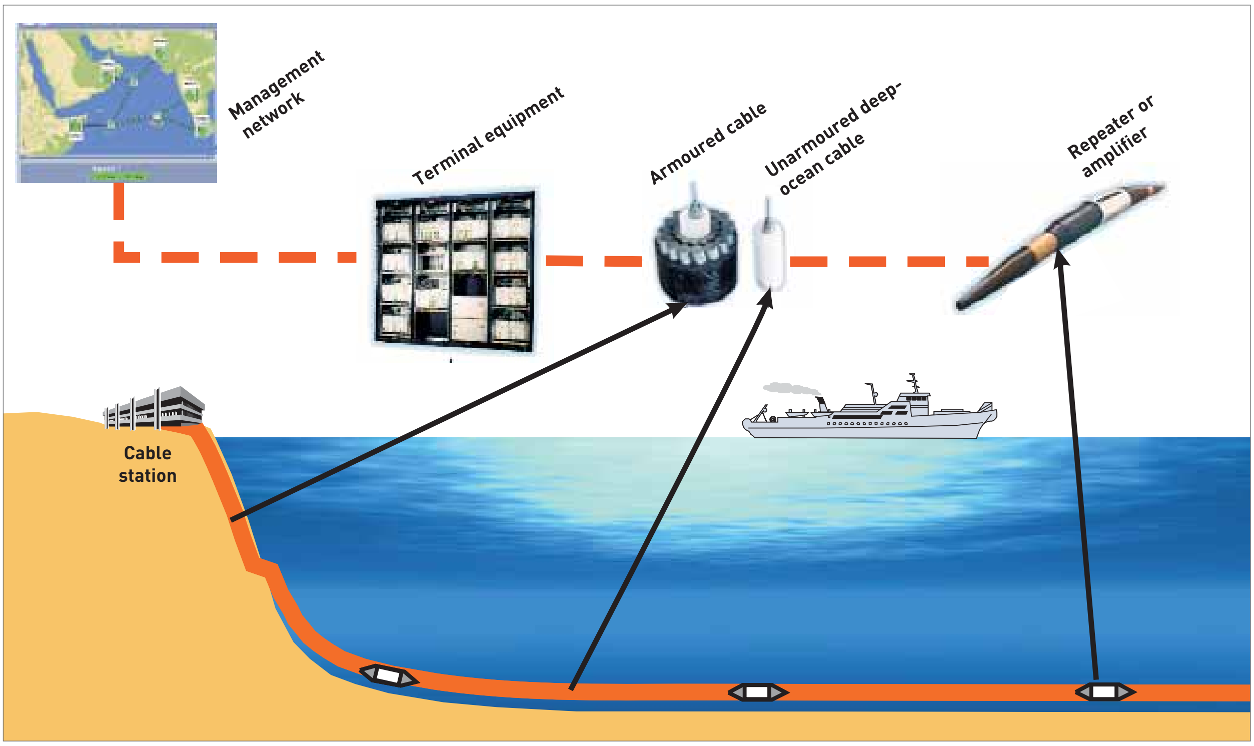
FROM COAST DOWN TO c.1,000–1,500 m WATER DEPTH: THE NEED FOR PROTECTION

Cables that extend across the continental shelf (typically 0–130 m deep) to a depth range of c.1,000–1,500 m, are commonly buried below the seabed to protect them from damage by other seabed users (Chapter 7). The most effective method of burial is by *sea plough* (Figure 3.4). As a cable approaches the seabed, it is fed through the plough, which inserts the cable into a narrow furrow. Different plough designs are available to suit various bottom conditions, e.g. the traditional plough-share is well suited for muddy substrates, whereas sandy sediments may require a plough equipped with a water jet to cut a trench into which the cable is placed. Burial disturbs the seabed along the narrow path of the cable, and this is discussed in Chapter 5.

When towing a sea plough, the ship carefully controls its operations so that cable slack is kept to a practical minimum as it enters the plough. The aim is to lay the cable with near-zero slack, but with enough looseness to fall into the furrow. In areas where the cable crosses another cable or a pipeline, the plough must be either recovered or 'flown' over the crossed section and then re-deployed on the opposite side. These skipped sections may be buried later, either by divers or by a remotely operated vehicle (ROV) fitted with trenching and burial tools as well as video and navigational aids (Figure 3.5).

Even with the latest sea plough and ROV technology, there are areas of seabed where burial is either impractical or impossible, e.g. rugged, rocky zones (Figure 3.2). In such areas, cable pay-out must be regulated to minimize suspensions between rock ridges. At the same time, slack cannot be excessive because heavy, stiff armoured

Figure 3.3: Summary diagram of a submarine cable system. *Source: UK Cable Protection Committee.*



cables (necessary for such rugged areas) may form loops if pay-out tension is allowed to approach zero at the touch-down point.

Cable deployment may be followed by a post-lay inspection to ensure that the cable is emplaced correctly either on or into the seabed (Figure 3.6). In shallow water down to c.40 m depth, inspections may be carried out by divers, whereas deeper-water inspections are usually made by an ROV equipped with video and digital cameras whose images are viewed on the surface control vessel in real time (Figure 3.5).

Some areas of the shallow-water seabed are unsuitable for burial and where possible are avoided. However, where rocky areas or zones of high sediment mobility, e.g. surf zone, cannot be avoided, other forms of protection are available and include protective covers of rocks, concrete 'mattresses' and steel or plastic conduits, the choice of which will be dictated by operational and environmental considerations.

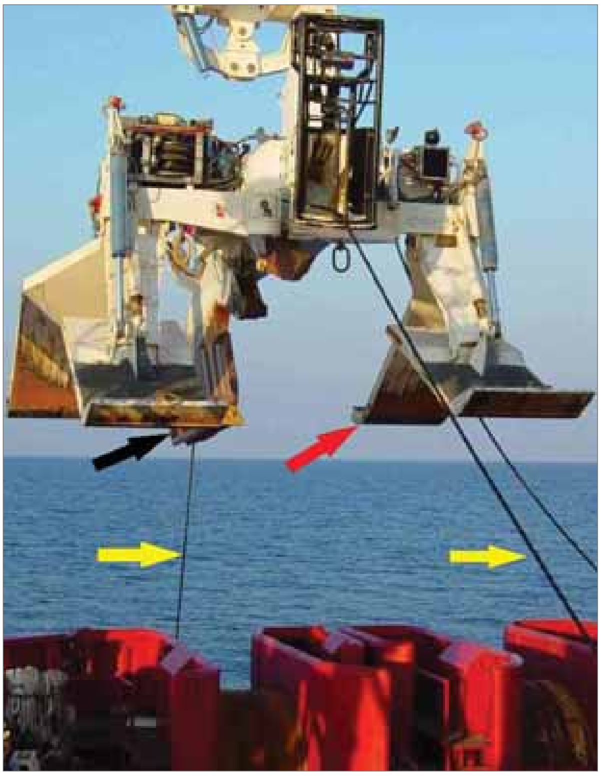


Figure 3.4: A sea plough about to be deployed from a cable ship. The fibre-optic cable (yellow arrows) is fed into a furrow cut by the plough-share (black arrow), which is towed across the seabed on skids (red arrow). *Source: Alcatel Submarine Network (ASN) now Alcatel-Lucent.*

Figure 3.5: TRITON ST-214 remotely operated vehicle (ROV), which is designed to assist burial of cables in areas inaccessible to a sea plough. It also performs cable inspections and recovery operations. *Source: Lonnie Hagadorn.*

BELOW c.1,500 m WATER DEPTH

Below a depth range of c.1,000–1,500 m, cables are deployed mainly on the seabed, although in rare instances burial may extend into deeper water (Chapter 7). This depth limit is presently the extent of modern bottom trawlers, but their forays into deeper water may necessitate burial in even greater water depths.

Typically, cable size and weight decrease with depth as the requirement for protective armour diminishes to zero. Such lightweight cables are easier to handle than armoured varieties, but cable slack must still be controlled carefully so that the cable follows the seabed contours. This may involve engineering 2–3 per cent slack into the laying procedure.

CABLE RECOVERY

Cables are retrieved from the seabed for repairs, replacement or removal (Alcatel-Lucent, 2008). Recovery may result from damage by human activities or natural events (Chapters 6 and 7), failure of components, cable age (design life is typically 20–25 years), or a need to clear congested routes. Recovery generally entails:

- location of the cable and, if a repair is required, identification of the faulted section;
- retrieval of the cable with specially designed grapnels deployed from the repair vessel;
- lifting to the surface for removal or repair.

During the haul-up process – sometimes from 1–3 m below the seabed – the strain on the cable is substantial. Thus recovery, like laying, is a complex process that takes into account a wide range of variables:

- the speed and angle of recovery;

- the ship's track along the cable route;
- the drag of the cable, which may have increased due to biological growth on the cable's exterior;
- water depth, current velocity, wave effects on vessel motion, and any natural or human-made objects, such as ship wrecks, that could potentially snag the ascending cable.

To aid this difficult process, manufacturers provide recovery tension tables that describe the maximum recommended recovery speed in a given water depth and at a given recovery angle for each cable type manufactured.

BEST PRACTICE

Most of the larger companies operating in the submarine cable industry typically work to standards and quality management systems set by the International Organization for Standards under the ISO 9000 and ISO 9001 schemes. In addition, the International Cable Protection Committee (ICPC) publishes recommendations on key issues such as cable routing, cable protection and cable recovery that are available to anyone on request. Although their observance is not mandatory, these recommendations are designed to facilitate quality improvement and are often cited by third parties as examples of best practice in the industry (ICPC, 2009). Guidelines relating to submarine cable activities are also published by the Submarine Cable Improvement Group (SCIG, 2009) and the UK Cable Protection Committee (UKCPC, 2009).

Figure 3.6: Image of a surface-laid cable taken during a post-lay inspection by an ROV. This image reveals the cable in the throes of burial by mobile gravel. *Source: Transpower New Zealand and Seaworks.*

4. International law

INTERNATIONAL CONVENTIONS

The invention of the submarine telegraph cable, and its successful use to span oceans and link nations, was immediately recognized as 'necessary to maintain the vitality of our modern international State system' and 'an interest of the highest order to States' (Twiss, 1880). The international community responded to this recognition with the International Convention for the Protection of Submarine Cables (1884) (Box 4.1).

BOX 4.1: INTERNATIONAL CONVENTION FOR THE PROTECTION OF SUBMARINE CABLES, 1884

The Cable Convention continues to be widely used in the cable industry. While its essential terms are included in the United Nations Convention on the Law of the Sea (UNCLOS), the Cable Convention remains the only treaty that provides the detailed procedures necessary to implement them. See:

- Article 5 special lights and day shapes displayed by cable ships; minimum distances ships are required to be from cable ships;
- Article 6 minimum distance ships are required to be from cable buoys;
- Article 7 procedures for sacrificed anchor and gear claims;
- Article 8 competency of national courts for infractions;
- Article 10 procedures for boarding vessels suspected of injuring cables and obtaining evidence of infractions.

Article 311(2) of UNCLOS recognizes the continued use of these provisions, which are compatible with and supplement UNCLOS.

BOX 4.2: CULPABLE NEGLIGENCE

The origin of the term 'culpable negligence' is found in Renault (1882), where reference is made to two early English cases: *Submarine Cable Company v. Dixon*, The Law Times, Reports-Vol. X, N.S. at 32 (5 March 1864) and *The Clara Killian*, Vol. III L.R. Adm. and Eccl. at 161 (1870). These cases hold that culpable negligence involves a failure to use ordinary nautical skill that would have been used by a prudent seaman facing the situation that caused the cable fault. Since the term 'culpable negligence' was adopted in UNCLOS without discussion, it is reasonable to assume that the same standard applies under UNCLOS.

This Cable Convention was the foundation of modern international law for submarine cables as contained in the Geneva Conventions on the High Seas 1958 (Articles 26–30) and Continental Shelf 1958 (Article 4) and, most recently, in the United Nations Convention on the Law of the Sea (1982) (UNCLOS). UNCLOS establishes the rights and duties of all states, balancing the interests of coastal states in offshore zones with the interests of all states in using the oceans. Coastal states exercise sovereign rights and jurisdiction in the exclusive economic zone (EEZ) and on the continental shelf for the purpose of exploring and exploiting their natural resources, but other states enjoy the freedom to lay and maintain submarine cables in the EEZ and on the continental shelf (Figure 4.1). In archipelagic waters and in the territorial sea, coastal states exercise sovereignty and may establish conditions for cables or pipelines entering these zones (UNCLOS, Article 79(4)). At the same time, the laying and maintenance of submarine cables are considered reasonable uses of the sea and coastal states benefit from them. Outside of the territorial sea, the core legal principles applying to international cables can be summarized as follows (UNCLOS, Articles 21, 58, 71, 79, 87, 112-115 and 297(1)(a)):

- the freedoms to lay, maintain and repair cables outside of territorial seas, including cable route surveys incident to cable laying (the term laying refers to new cables while the term maintaining relates to both new and existing cables and includes repair) (Nordquist *et al.*, 1993, p. 915);
- the requirement that parties apply domestic laws to prosecute persons who endanger or damage cables wilfully or through culpable negligence (Box 4.2);
- the requirement that vessels, unless saving lives or ships, avoid actions likely to injure cables;
- the requirement that vessels must sacrifice their anchors or fishing gear to avoid injury to cables;
- the requirement that cable owners must indemnify vessel owners for lawful sacrifices of their anchors or fishing gear;

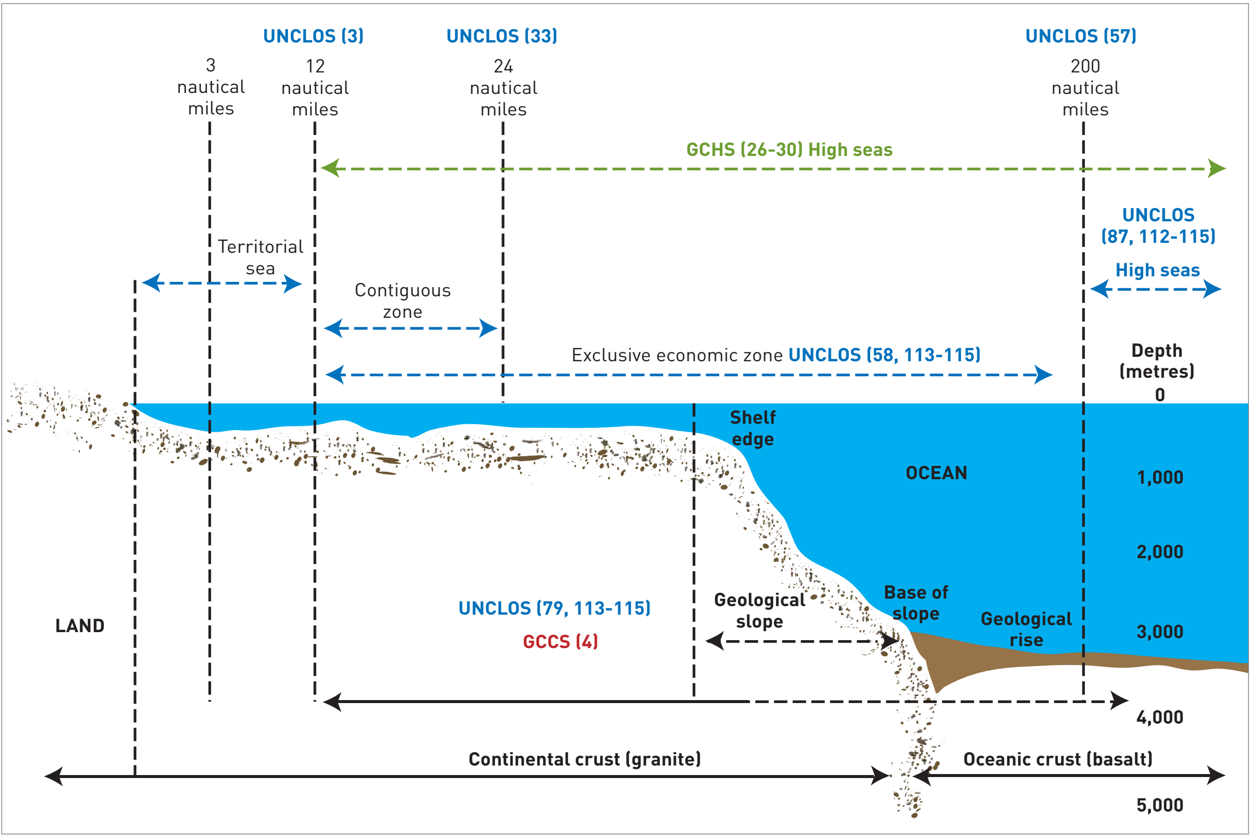
- the requirement that the owner of a cable or pipeline, who in laying or repairing that cable or pipeline causes injury to a prior laid cable or pipeline, indemnify the owner of the first laid cable or pipeline for the repair costs;
- the requirement that coastal states along with pipeline and cable owners shall not take actions which prejudice the repair and maintenance of existing cables.

These traditional rights and obligations were carefully codified by the UNCLOS drafters who were familiar with the historical state practice of cables. Parts IV to VII of UNCLOS set out the rights and obligations in the following UNCLOS designated zones: archipelagic waters, the EEZ, the continental shelf and the high seas (Figure 4.1). UNCLOS treats all cables the same, whether they are used for telecommunications or power transmission or for commercial, military or scientific purposes.

While natural occurrences such as submarine landslides or turbidity currents occasionally damage submarine cables, the most common threat to cables is other human activities, especially bottom fishing (Chapter 7). In many countries, careful route planning helps to avoid damage to cables and to cultural seabed features (Wagner, 1995). With respect to potential adverse impacts caused by submarine cables, UNCLOS indirectly takes into account their potential environmental impact by distinguishing cables from submarine pipelines, i.e. on the continental shelf it allows a coastal state to delineate a route for a pipeline but not for a cable (Article 79(3)). The reason for this distinction is that there is clearly a need to prevent, reduce and control any pollution that may result from pipeline damage. By comparison, damage to a submarine telecommunications cable is unlikely to involve pollution (Nordquist *et al.*, 1993, p 915), but may significantly disrupt international communications and data traffic.

More generally, UNCLOS, in its preamble, recognizes the desirability of establishing 'a legal order for the seas and oceans which will facilitate international communication, and will promote the peaceful uses of the oceans and seas, the equitable and efficient utilization of their resources, the conservation of their living resources, and the study, protection and preservation of the marine environment'.

Figure 4.1: Legal boundaries of the ocean from territorial sea to exclusive economic zone and onto the high seas (figures in parenthesis refer to treaty articles). *Source: D. Burnett.*



Submarine cables clearly facilitate international communication, along with freedoms of navigation and overflight. Part XII of UNCLOS establishes the legal duty of all states to protect and preserve the marine environment (Article 192). It establishes a general legal framework for this purpose, which balances economic and environmental interests in general as well as the interests of coastal states in protecting their environment and natural resources and the rights and duties of other states. To flesh out the framework, it requires states to adopt more detailed measures to ensure that pollution from activities under their control does not cause environmental damage to other states or areas beyond national jurisdiction. States shall, consistent with the rights of other states, endeavour to observe, measure, evaluate and analyse, by recognized scientific methods, the risks or effects of pollution of the marine environment (Article 204).

CABLES AS CRITICAL INFRASTRUCTURE

An emerging trend is for states to treat international cables in national maritime zones as critical infrastructure that deserves strong protection to complement traditional international cable law. In that vein, Australia, consistent with international law, has legislated to protect its vital cable links by creating seabed protection zones that extend out to 2,000 m water depth. Bottom trawling and other potentially destructive fishing practices, as well as anchoring, are prohibited inside these zones. Three international cables carry around 99 per cent of Australia's voice and data traffic and in 2002 were worth more than AU$5 billion a year to the country's economy (Telecommunications and Other Legislation Amendment (Protection of Submarine Cables and Other Measures) Act 2005; proposed regulations for submarine cables off Sydney, New South Wales (August 2006)). New Zealand has also enacted legislation that established no-fishing and no-anchoring zones around cables (Submarine Cable and Pipeline Protection Act (1966)). The trend is expected to continue because most nations depend on cables for participating in the global economy and for national security, e.g. the United States relies on cables for over 95 per cent of its international voice and data traffic, only 7 per cent of which could be carried by satellites if the cables were disrupted (Burnett, 2006). These developments sometimes go hand in hand with conservation, as restrictions on trawling to prevent cable damage can also provide direct benefits for biodiversity by protecting vulnerable seabed ecosystems and species such as corals and sponges (CBD, 2003).

Since UNCLOS, the parties to the UNESCO Convention on Underwater Cultural Heritage (2001) agreed to exempt cables from that treaty because of the specific provisions of UNCLOS and the agreement of the parties that cable laying and maintenance posed no threat to underwater cultural heritage.

Figure 4.2: Rights and obligations relating to submarine cables in the world's oceans can be enforced in national courts or in the International Tribunal for the Law of the Sea, shown in session in Hamburg, Germany. *Source: Stephan Wallocha.*

There are numerous international conventions that build on the UNCLOS framework to further specify requirements for ocean uses such as international shipping or fisheries, but not for submarine cables. Other treaties elaborate on what states should generally do to protect and preserve the marine environment and, as embodied in the 1992 Convention on Biological Diversity (CBD), to conserve and sustainably use marine biodiversity. All of these conventions function in accordance with the UNCLOS framework, both within and beyond national jurisdiction. However, there are no conventions that further elaborate the legal framework for cables established by UNCLOS and the earlier Cable Convention.

The laying and maintenance of telecommunications cables is a reasonable use of the sea, and in 159 years of use, there has been no irreversible environmental impact. UNCLOS and state practice have provided adequate governance for international cables outside of national waters, and state practice increasingly recognizes the importance of protecting cables from activities that could damage them. The corresponding benefits of cable protection zones for biodiversity conservation have also been recognized. Yet increasing use of the oceans and seabed is likely to result in more conflicts between users (Figure 4.2). This may require future changes in the existing international legal regime. Careful planning may also be necessary to avoid adverse impacts on vulnerable seafloor ecosystems and biodiversity. Consistent with past practice and recognizing the importance of cables to the world's infrastructure, any change to the existing international law requires express provisions in an international treaty.

5. Environmental impacts

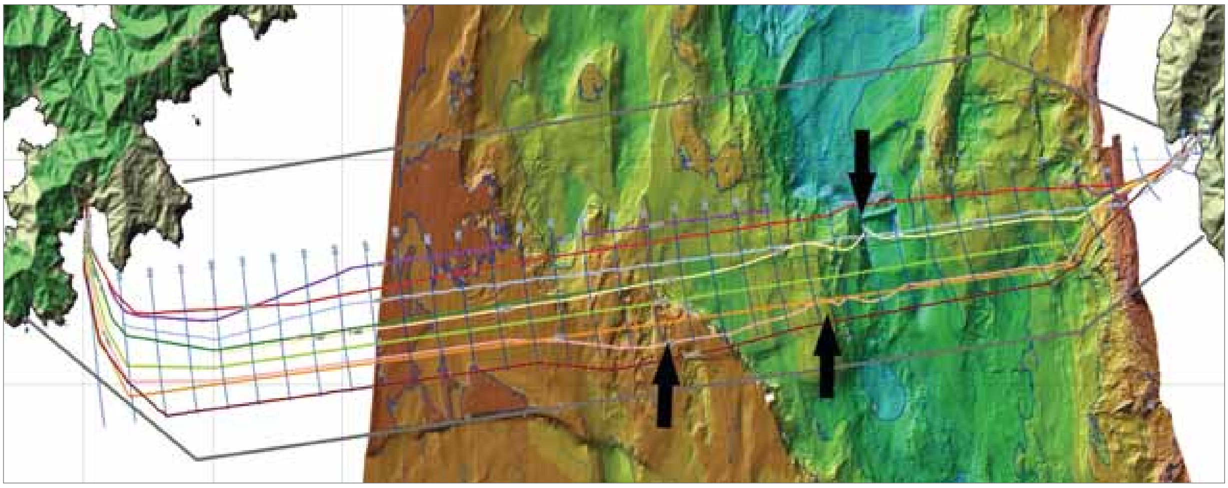
The total length of fibre-optic cables in the world's oceans is c.1 million km (J. Annals, Global Marine Systems Ltd, pers. comm., 2007). In terms of physical size, a modern cable is small (Chapter 2). The deep-ocean type has a diameter of 17–20 mm and its counterpart on the continental shelf and adjacent upper slope is typically 28–50 mm diameter because of the addition of protective armouring. Despite this small footprint, fibre-optic cables may still interact with the benthic environment. This chapter begins with an overview of the procedures for evaluating those interactions via the environmental impact assessment (EIA) process. This is followed by a synopsis of those environmental interactions of cables laid on and into the seabed, using the peer-reviewed science literature supported by open-file and published reports. The chapter concludes with some general considerations regarding cables and the environment.

ENVIRONMENTAL IMPACT ASSESSMENTS

For some countries, domestic law and regulations require an analysis of the project's effects on the natural environment. The report that is subsequently produced is commonly referred to as an environmental impact assessment (EIA). The breadth of content, level of detail and time required to undertake an EIA in relation to a proposed submarine cable project varies considerably from country to country. Nevertheless, the principle of assessing a project's effect on the environment is well established in Europe, Australasia, North America and parts of Asia and Africa.

The purpose of an assessment is to ensure that any environmental effects of cable laying and maintenance are taken into account before authorization is provided to lay a cable on the seabed (e.g. Hong Kong Environmental Protection Department, 2002; Monterey Bay National Marine Sanctuary, 2005; North American Submarine Cable Association, 2008). However, the extent to which a permit application requires an EIA depends on the regulatory process. It can range from the provision of relevant technical information and a statement of compliance with environmental accreditation, to a brief environmental review, to a comprehensive analysis that includes formal public and/or governmental consultation. Schedules for completing an assessment range from a few weeks to a year or longer. This depends on the quantity and quality of data needed, the level of documentation and consultation required, and the presence of sensitive environmental resources within the project's bounds.

Figure 5.1: Telecommunications and power cables laid on the seabed surface of Cook Strait, New Zealand, because the presence of rock and the constant movement of sediment by powerful tidal flows make it impractical to bury them. Protection is afforded by a legal cable protection zone (boundaries are grey lines on multibeam image). Even so, fibre-optic cables were displaced (arrows) by illegal fishing prior to full-time boat patrols of the zone, when such incidents ceased. *Source: Transpower New Zealand, Seaworks and NIWA.*



A formal EIA typically has five components:

1. description of the proposed operation;
2. description of the receiving environment (covering all relevant physical, geological, biological and anthropogenic/socio-economic factors);
3. evaluation of potential effects on the environment;
4. assessment of mitigating measures needed to reduce any effects to an environmentally acceptable level (i.e. spatial or temporal limitations, replacement, re-establishment or restoration of affected environments);
5. assessment of any monitoring measures needed to ensure that the extent of an effect (mitigated or otherwise) is maintained at an acceptable level.

This documentation is usually followed by a non-technical summary, which is a 'reader-friendly' synopsis for general circulation in a consultation process. As well as evaluation of existing data, an EIA may require field surveys that involve seabed mapping and sampling of sediments, rocks, fauna, flora and biochemistry (Chapter 3).

EIAs for cable operations are rare and are generally limited to a coastal state's territorial sea. The European Union EIA Directive currently does not explicitly impose an EIA requirement on cable-laying projects. That, of course, does not discount the possibility of an EIA being required as a result of a submarine cable planning application. Indeed, such applications are most likely to be routinely reviewed by the appropriate authority.

CABLES ON THE SEABED

Modern cables are usually buried into the seabed at water depths down to c.1,500 m as a protective measure against human activities (Chapters 3 and 7). However, some shallow-water cables may be placed on the seabed in areas unsuitable for burial, e.g. rock or highly mobile sand (Figure 5.1). For water depths greater than c.1,500 m, deployment on the seabed is the preferred option (Chapter 3).

Surveys

Cable route surveys rely primarily on acoustics-based echo-sounding, sonar and seismic systems. These focus on the seabed surface and, where burial is concerned, the few metres of sediment below the seabed. Accordingly, high-frequency low-energy acoustic systems are used to provide the necessary precision and detail to define a suitable route. Given our incomplete knowledge of the different responses of marine animals to different sources of noise (National Research Council, 2003), cable survey equipment is regarded as posing only a minor risk to the environment (SCAR, 2002) compared to prolonged high-energy mid-range sonar systems, which may be associated with strandings of some whale species (Fernandez *et al.*, 2005) and are the subject of ongoing research (Claridge, 2007).

Physical interactions

Surface-laid cables may physically interact with the seabed under natural or human influences. Continental shelves are typically exposed to wave and current action, including tidal flows that move sediment and result in the burial, exposure or even undermining of a cable (Figure 5.1; Carter and Lewis, 1995; Carter *et al.*, 1991). Where undermining is significant, the suspended cable can vibrate or strum under the water motions. Such actions may abrade the rocks supporting the suspension and the cable itself. Observed suspensions off California indicate that rock abrasion occurs mainly in the zone of frequent wave activity in water depths of less than c.20 m (Kogan *et al.*, 2003, 2006); abrasion marks ranged from 6 to 45 cm wide. Where the suspensions are long lived, they can be colonized by encrusting marine biota (Figure 5.2) that can biologically cement the cable to the rock suspension points.

Cables undergo self-burial that is either temporary or permanent. Where routes traverse fields of mobile sand waves, burial takes place as the sand-wave crest passes across the cable. Exhumation may follow with the passage of the sand-wave trough (Allan, 2000). Temporary burial

Figure 5.2: Surface-laid submarine cable, which has served as a substrate for the growth of epifauna. *Source: Nigel Irvine.*

also occurs nearshore, where 'fair-weather' accumulation of sand may be interrupted by storm-forced waves and currents that erode the substrate to expose a previously buried cable (Carter and Lewis, 1995). In zones of high sediment accumulation, cables can be rapidly buried by depositing sediment or simply settle into a soft substrate. Off California, for example, about half of a 95 km-long scientific coaxial cable was covered by sediment in the eight years following its surface installation (Kogan *et al.*, 2003).

Bottom trawl fishing and ships' anchoring can displace and/or damage cables (NOAA, 2005). To protect against such mishaps, cables are routinely buried beneath the seabed (Chapters 3 and 7). Where burial is impractical, a cable protection zone may be enforced whereby all potentially damaging human activities are prohibited (Figure 5.1; e.g. ACMA, 2007; Transpower and Ministry of Transport, 2008). Such measures are only as good as their enforcement, which may entail constant surveillance, including vessel patrols and electronic monitoring of all ship movements. Dialogue with other seabed users, along with public education regarding the importance of submarine cables, is also an effective protection measure (Chapter 7).

Benthic biota

Any interaction of cables with seabed life may be evaluated by assessing and monitoring the biota before and after cable installation (Andrulewicz *et al.*, 2003) or, in the case of installed cables, by comparing the biota at sites near and distant from a cable (Grannis, 2001; Kogan *et al.*, 2003). In addition, there are reports of epifauna and epiflora that live on the cables themselves (Figure 5.2; Ralph and Squires, 1962; Levings and McDaniel, 1974).

Overall, those studies demonstrate that cables have no or minimal impact on the resident biota. On the basis of 42 hours of video footage, the comprehensive study of Kogan *et al.* (2003, 2006) showed no statistical difference in the abundance and distribution of 17 animal groups living on the seabed within 1 m and 100 m of a surface-laid coaxial scientific cable. Likewise, 138 sediment cores with an infauna of mainly polychaete worms, nematodes and amphipods showed that the infauna was statistically indistinguishable whether near or distant from the cable. The main difference associated with the cable was that it provided a hard substrate for the attachment of anemones (Actiniaria). These organisms were abundant where the cable traversed soft sediment that normally would be unsuitable for such animals (Figure 5.3). Fishes, especially flat fishes, were more common close to the cable at two observational sites where small patches of shell-rich sediment had formed, probably in response to localized turbulence produced by current flow over the cable.

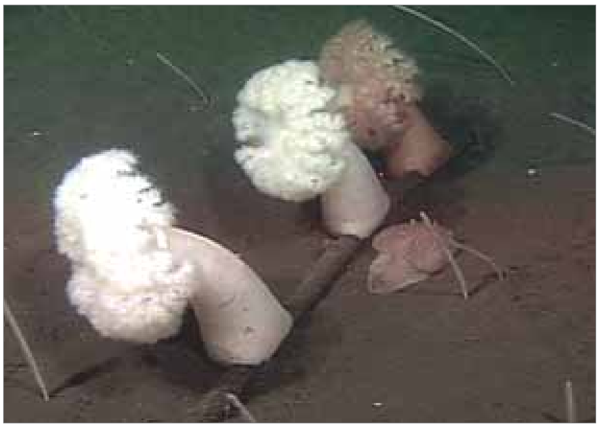


Figure 5.3: The exposed ATOC/Pioneer Seamount cable with attached anemones (*Metridium farcimen*) at c.140 m water depth. The cable provides a hard substrate on an otherwise soft seabed. The thin, erect organisms are sea pens (*Halipteris* sp.), and the mollusc *Pleurobranchaea californica* is next to the 3.2 cm wide cable. *Source: Monterey Bay Aquarium Research Institute (MBARI).*

Marine mammals and fish

Records extending from 1877 to 1955 reveal that 16 faults in submarine telegraph cables were caused by whales (Heezen, 1957; Heezen and Johnson, 1969). Thirteen of the faults were attributed to sperm whales, which were identified from their remains entwined in the cables. The remaining faults were caused by a humpback, killer and an unknown whale species. In most instances, entanglements occurred at sites where cables had been repaired at the edge of the continental shelf or on the adjacent continental slope in water depths down to 1,135 m. However, whale entanglements have nowadays ceased completely. In a recent review of 5,740 cable faults recorded for the period 1959 to 2006 (Wood and Carter, 2008), not one whale entanglement was noted (Figure 5.4). This cessation occurred in the mid-1950s during the transition from telegraph to coaxial cables, which was followed in the 1980s by the change to fibre-optic systems.

The absence of entanglements since the telegraph era reflects the following developments in cable design and laying:

- advances in design, especially the achievement of torsional balance, lessened the tendency of coaxial and fibre-optic cables to self-coil on the seabed;
- accurate seabed surveys, coupled with improved vessel handling and laying techniques, reduced suspensions and loops by laying cables under tension while following the seabed topography and avoiding excessively rough rocky substrates;

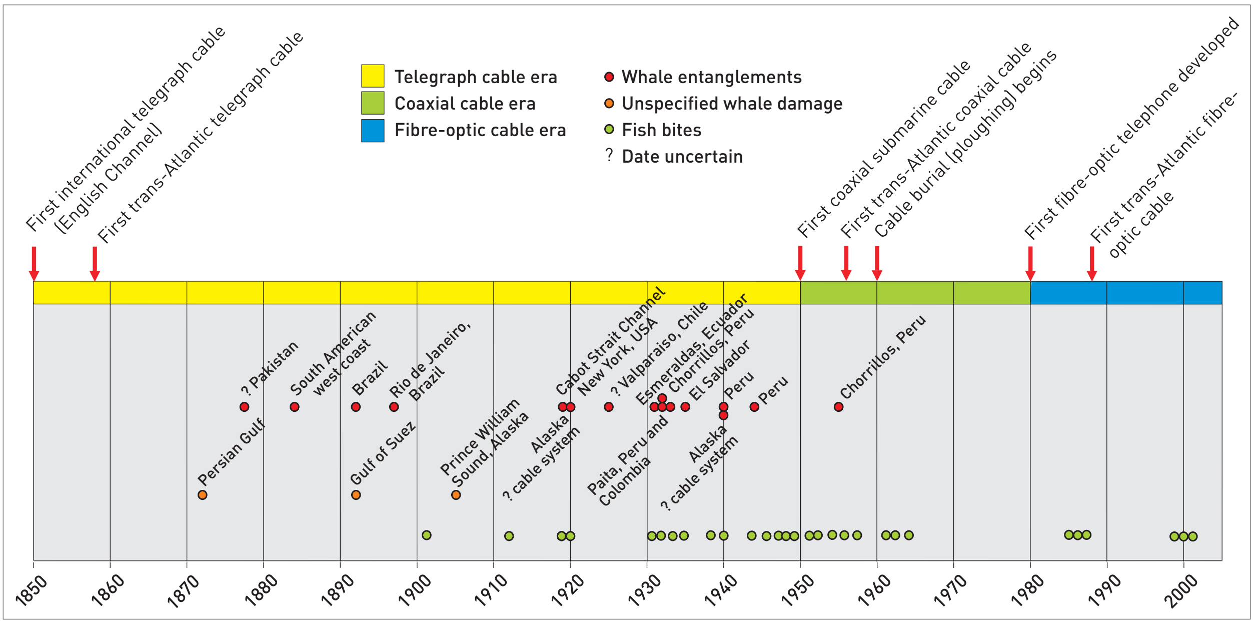


Figure 5.4: Interaction of whales and fish with submarine cables over time. The cessation of whale entanglements coincided with the improved design and laying techniques of the coaxial and fibre-optic eras. In contrast, fish bites (including those of sharks) have continued. *Source: Wood and Carter (2008) and IEEE Journal of Oceanic Engineering.*

- burial of cables into the seabed on the continental shelf and slope down to c.1,500 m water depth, which is the typical maximum diving limit of sperm whales (Watkins *et al.*, 2002);
- fault repair techniques that are designed to minimize slack cable and, if the repaired section is on the continental shelf or slope, burial beneath the seabed, usually with the assistance of an ROV.

Is the cessation of whale entanglements since 1959 possibly a consequence of non-reporting? This is unlikely because:

- whale entanglements prior to 1959 were reported in the scientific literature (Heezen, 1957; Heezen and Johnson, 1969);
- interactions with other marine animals since 1959 have been reported (ICPC, 1988; Marra, 1989);
- cable repairs are undertaken by a few specialized maintenance groups contracted to many cable owners and operators, and are therefore required to operate at high standards, which would reduce the chance of non-reporting;
- an event such as a whale capture is unlikely to escape media attention when electronic communication is so freely available, even at sea.

Fish, including sharks, have a long history of biting cables as identified from teeth embedded in cable sheathings (Figures 5.4 and 5.5). Barracuda, shallow- and deep-water sharks and others have been identified as causes of cable failure (ICPC, 1988; Marra, 1989). Bites tend to penetrate the cable insulation, allowing the power conductor to ground with seawater. Attacks on telegraph cables took place mainly on the continental shelf and continued into the coaxial era until c.1964. Thereafter, attacks occurred at greater depths, presumably in response to the burial of coaxial and fibre-optic cables on the shelf and slope. Coaxial and fibre-optic cables have attracted the attention of sharks and other fish. The best-documented case comes from the Canary Islands (Marra, 1989), where the first deep-ocean fibre-optic cable failed on four occasions as a result of shark attacks in water depths of 1,060–1,900 m (Figure 5.5). Reasons for the attacks are uncertain, but sharks may be encouraged by electromagnetic fields from a suspended cable strumming in currents. However, when tested at sea and in the laboratory, no clear link between attacks, electromagnetic fields and strumming could be established. This lack of correlation may reflect differences between the behaviour of the deep-water sharks responsible for the bites and that of the shallow-water species used in the experiments. Whatever the cause, cables have been redesigned to improve their protection against fish biting.

Leaching from cables

Modern deep-water fibre-optic cables are composed of several pairs of hair-like glass fibres, a copper power conductor and steel wire strength member, which are all sheathed in high-density polyethylene. Where extra protection is required, as for areas of rocky seabed or strong wave and current action, additional steel wire armour is added (Chapter 2). No anti-fouling agents are used (Emu Ltd, 2004). Of these materials, cable-grade polyethylene is essentially inert in the ocean. Processes such as oxidation, hydrolysis (chemical breakdown in water) and mineralization are extremely slow; the total conversion of polyethylene to carbon dioxide and water will take centuries (Andrady, 2000). The effects of ultraviolet light (UV-B), the main cause of degradation in most plastics, are minimized through the use of light-stabilized materials, burial into the seabed and the natural reduction in light penetration through the upper ocean, where the photic zone rarely extends beyond 150 m depth. Any mechanical breakdown of a cable's plastic sheathing to fine-grained particles on the energetic continental shelf – a potential hazard for marine life (Allsop *et al.*, 2006 and references therein) – is minimized by armouring and burial.

With respect to other cable components, data on their behaviour in seawater are sparse, with the exception of a study under way at Southampton University, UK (Collins, 2007). Various types of fibre-optic cable were immersed in containers with 5 litres of seawater, which was tested for copper, iron and zinc – potential leachates from the conductors and galvanized steel armour. Of these elements only zinc passed into the seawater, yielding concentrations of less than 6 parts per million (ppm) for intact cables and less than 11 ppm for cut cables with exposed wire armour ends. The amount of leaching declined after c.10 days. Bearing in mind that tests were carried out in a small, finite volume of seawater, zinc leachate in the natural environment would be less due to dilution by large volumes of moving seawater. Furthermore, zinc is a naturally occurring element in the ocean, with concentrations in fish and shellfish ranging from 3 to 900 ppm (Lenntech, 2007).

CABLES INTO THE SEABED

Installation of cables into the seabed can disturb the benthic environment. Compared to other offshore activities such as bottom trawling, ship anchoring and dredging, disturbance related to cable burial is limited in its extent, and is a non-repetitive procedure, unless a cable is damaged (Chapter 3). The decommissioning and recovery of a buried system may also result in benthic disturbance, but again it is of limited extent and relatively infrequent, reflecting the 20–25 year design life of a fibre-optic cable. The following discussion examines the type and extent of seabed disturbance associated with cable installation, maintenance and decommissioning, followed by a brief overview of seabed recovery after disturbance.

Seabed disturbance

Route clearance

Prior to installation, any debris is cleared from a cable route by deployment of a ship-towed grapnel (NOAA, 2005; NSR Environmental Consultants, 2002). This tool penetrates 0.5–1.0 m into soft sediment and is generally not used in rocky areas. In accord with modern practice, the location of the grapnel is carefully monitored to ensure that burial follows the grapnel route as closely as possible so that the cable is installed in a debris-free zone.

Ploughing

As a plough passes across the seabed, the share opens a furrow, inserts the cable and allows sediment to fall back, thereby filling the fissure (Allan, 1998). However, the precise nature of this disturbance will vary with substrate type, depth of burial and plough type (Hoshina and Featherstone, 2001; Jonkergrouw, 2001; Mole *et al.*, 1997; Turner *et al.*, 2005). In nearshore zones including tidal flats, special ploughs are available to lessen disturbance to, for example, eelgrass and seagrass beds (Ecoplan, 2003). Disturbance is also minimized by drilling conduits through which a cable may pass beneath biologically sensitive coastal areas (Austin *et al.*, 2004). On the continental shelf, burial to c.1 m depth in soft to firm sediment typically leaves a ploughed strip, c.0.3 m wide, in which the cable is entirely covered. However, burial in consolidated substrates may result in only partial closure of the furrow, with displaced sediment deposited at the furrow margins (NOAA, 2005). The skids that support the plough can also leave their footprint on the seabed, particularly in zones of soft sediment (Chapter 3). Potential effects are increased sediment compaction and the disruption of marine fauna. Overall, the disturbance strip produced by the plough-share and skids in direct contact with the seabed ranges from c.2 m to c.8 m wide, depending on plough size.

Figure 5.5: The crocodile shark (*Pseudocarcharias kamoharai*) is a small species that grows to just over 1 m long. On the basis of teeth embedded in the Canary Islands fibre-optic cable, it was found to be a main instigator of the bite-related faults. *Source: National Marine Fisheries Service, NOAA.*

Jetting

This method is used to bury cables that are already laid. Some systems use a combination of ploughing and jetting for burial but, in general, jetting is favoured for deep parts of a route where steep slopes or very soft sediment are unfavourable for ploughing (Hoshina and Featherstone, 2001; Jonkergrouw, 2001). It is also used to rebury repaired sections. Modern post-lay burial relies on an ROV that is equipped with jets to liquefy the sediment below the cable, allowing it to sink to a specified depth (Chapter 3). The width of disturbance zones associated with jetting (liquefaction and coarse sediment redeposition) is typically about 5 m (Ecology and Environment, 2001), but fine-grained silt and clay may be dispersed further afield in plumes of turbid water. Organisms directly within the zone of liquefaction can be damaged or displaced, whereas biota near the jetting zone may receive the resuspended sediment (NOAA, 2005). Any effect on and recovery of the biota will depend on a suite of variables including the amount and particle size of the suspended sediment, ambient current and wave conditions, seabed topography, the nature of the benthic biota and the frequency of natural disturbances (see *Seabed recovery*).

Cable repairs

Around 70 per cent of all cable failures associated with external aggression are caused by fishing and shipping activities in water depths shallower than 200 m (Kordahi and Shapiro, 2004). Accordingly, cables are buried for protection, an action which, together with an increased awareness of cables by other seabed users, has produced a marked fall in the number of faults per 1,000 km of cable. Faults related to component failure have also decreased in response to improved cable system design (Featherstone *et al.*, 2001). Nevertheless, faults still occur and require repair. For buried cables, the repair procedure relies on towing a grapnel across the path of the cable, cutting the cable and retrieving both ends. Onboard the repair ship, a new section may be inserted or 'spliced' to replace the damaged cable. The repaired section is re-laid on the seabed at right angles to the original route so as to minimize slack produced by insertion of the splice (Drew and Hopper, 1996). The repair is then reburied by a jet-equipped ROV (e.g. Mole *et al.*, 1997). Where water depths permit, ROVs may also be used to retrieve damaged cables both on and below the seabed. As this technique is likely to require no or few grapnel runs, seabed disturbance is reduced.

Cable removal

As cables reach the end of their design life or become redundant due to technological advances, their removal from the seabed may be considered. In the case of a buried cable, its removal may result in disturbance, the extent of which has been assessed for offshore UK by Emu Ltd (2004). In essence, as a cable is pulled from the seabed it disturbs the sediments and associated benthic fauna. The degree of disturbance is closely related to the type of substrate, with soft sandy and muddy sediments suffering little or no impact, whereas consolidated substrates, such as stiff clay and chalk, may create fine-scale rough topography from fragments of consolidated material ejected during cable extraction. For bedrock, a cable is usually laid on the rocky surface if outcrops cannot be avoided. In that context, the cable may support an epifauna which would be lost during a recovery procedure. It may then be deemed prudent to leave the cable in place in order to preserve the epifauna.

How much do submarine cables affect the environment?

A sense of context

Disturbances and impacts caused by cable laying and repairs must be viewed in the context of the frequency and extent of these activities. Clearance of debris from a path proposed for cable burial is usually followed within days to weeks by actual burial. Unless a cable fault develops, the seabed may not be disturbed again within the system's design life. Furthermore, the one-off disturbance associated with cable placement is restricted mainly to a strip of seabed less than 5–8 m wide. For comparison, bottom trawl and dredge fishing operations are repetitive and more extensive (e.g. National Research Council, 2002; UNEP, 2006). A single bottom trawl can be tens of metres wide, sweep substantial areas of seabed in a single operation and is likely to be repeated over a year at the same site. As noted by NOAA (2005), a single impact, such as a cable burial, is preferred to continuous, multiple or recurring impacts.

Seabed recovery

Seabed disturbance related to cable operations most commonly occurs in the burial zone from 0 to c.1,500 m water depth. This is also the main range of disturbance resulting from human activities as well as natural forces such as storm waves and currents, etc. (UNEP, 2006; Nittrouer *et al.*, 2007). The time taken for the seabed to recover depends on the natural dynamics of the various environments and the type of disturbance. Much of our knowledge of seabed recovery is based on studies of areas disturbed by fishing or large natural perturbations (e.g. National Research Council, 2002; Kroeger *et al.*, 2006 and references therein) with additional information provided by several cable-specific studies (e.g. Andrulewicz *et al.*, 2003; Grannis, 2001; NOAA, 2005).

Coastal zone

For coastal wetlands and inter-tidal zones, the use of various techniques to meet different environmental conditions has helped to reduce disturbance. A specially designed, low-impact vibrating plough was used to bury a cable through salt marshes along the Frisian coast, Germany. A post-lay monitoring survey recorded the re-establishment of salt marsh vegetation within one to two years and full recovery at most monitoring sites within five years (Ecoplan, 2003). In Australia, cables crossing seagrass beds were placed in narrow slit trenches (40 cm wide) that were later replanted with seagrass removed from the route prior to installation (Molino-Stewart Consultancy, 2007). A similar technique was used for eelgrass beds in Puget Sound where cables were also installed in conduits drilled under the beds to minimize disturbance (Austin *et al.*, 2004). Soft sediment communities in artificially disturbed muddy mangrove flats recovered in two to seven months depending on the intensity of the disturbance (Dernie *et al.*, 2003). With respect to high-energy sandy coasts, any physical disturbance is usually removed within days to weeks through natural wave and current action (e.g. CEE, 2006; Carter and Lewis, 1995).

Continental shelf and slope

The continental shelf has a range of substrates and habitats that reflect:

- the amount of sediment discharged from rivers and produced directly in the ocean and seabed through biological growth;
- wave and current action that erodes, disperses and deposits sediment;
- the local geology (e.g. Nittrouer *et al.*, 2007).

Of course, these influences are themselves ultimately controlled by the climate, regional oceanography and tectonic framework. With respect to unconsolidated sediment, the amount of wave energy required to mobilize it decreases with water depth. Thus, on the inner continental shelf (typically less than 30 m deep), sand is frequently moved by swell in the presence of local currents. Sediment movement is less frequent on the middle shelf (c.30 to 70 m depth), occurring mainly during storms when swell and current activity intensifies. Finally, sediment movement on the outer shelf (c.70 m to the shelf edge at an average depth of c.130 m) is infrequent, being controlled mainly by the passage of major storms. However, movement may be more frequent at the shelf edge *per se*, where the steepened topography intensifies local currents and causes internal waves (i.e. waves formed along density surfaces under the ocean surface) to break like a normal wave on a beach.

This generalized picture of shelf behaviour is influenced and sometimes over-ridden by local conditions. For instance, the powerful tides in the North Sea, Straits of Messina, Bass Strait and Cook Strait, frequently move sediment at most shelf depths. Whatever the forcing mechanism, physical restoration of the seabed is most rapid on those shelves with a substantial supply of sediment and moderate to high wave or current action. Thus any cable-related disturbance of sandy substrates on the inner shelf is usually rectified within days to months (CEE, 2006; DeAlteris *et al.*, 1999; NOAA, 2007). Likewise, the benthic communities also recover quickly because they have natural adaptive behaviours gained from an environment subject to frequent change. Bolam and Rees (2003), for instance, show that benthic macrofaunal communities in energetic zones recovered within nine months following the dumping of dredge spoil.

Where possible, cable routes avoid zones of rocky reef because of operational difficulties in protecting cables on hard substrates and potential disturbance of reef ecosystems (e.g. Ecology and Environment, 2001; Science Applications International, 2000).

On the middle shelf (c.30–70 m depth), zones of disturbance are likely to remain longer due to less frequent wave and current activity (e.g. NOAA, 2005). However, if local currents are active, sediment movement will restore equilibrium, as observed in the Baltic Sea where a cable trench collected sand to the point that, one year after laying, any physical dislocation of the seabed was erased (Andrulewicz *et al.*, 2003). Furthermore, the post-lay inspection failed to detect significant changes in the composition, abundance and biomass of benthic animals. In the case of muddy substrates, cable-related disturbances may persist longer than in mobile sand settings. In Stellwagen National Marine Sanctuary off Massachusetts, USA, slow sedimentation had not completely infilled a cable trench one year after ploughing (Grannis, 2001). However, there was no detectable effect on the epifauna, which appears to have recovered in the one-year period. Where the cable trench passed through an area of active bottom fishing grounds, the epifauna was more abundant within the trench; a feature that was attributed to fishing-induced resuspension of fine sediment within the trench to expose gravel fragments that provided substrates for epifaunal colonization. A similar response was noted in a cable trench in Olympic National Marine Sanctuary off Washington State, USA (NOAA, 2005), where exposed consolidated sediment attracted an epifauna which, in this case, differed from the benthos in undisturbed sediment.

The speed at which a trench infills depends on:

- its depth of incision;
- the sediment supply and wave or current action to carry the material to the trench, which tends to act as a sediment sink;
- the degree of sediment consolidation, with soft sediments tending to respond readily to wave and

current action whereas consolidated materials will be more resistant.

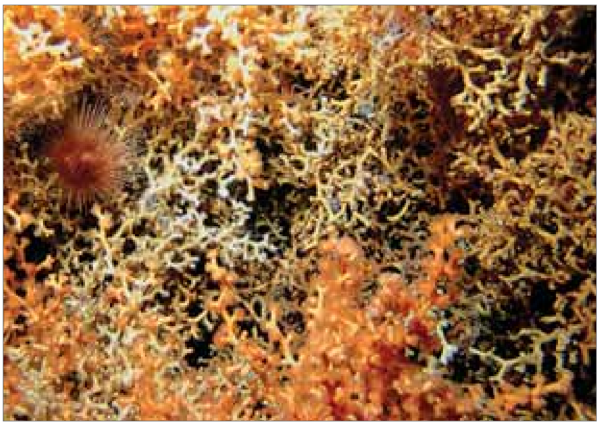
Continental shelves receiving large amounts of river mud and sand, such as those bordering the Pacific Ocean (Milliman and Syvitski, 1992), can expect several millimetres to centimetres of sediment to deposit each year. This appears to be the case on the Californian shelf, where repeated surveys of a cable trench have shown persistent accumulation and burial over four years (California Coastal Commission 2005, 2007).

On the outer shelf and upper slope (more than 70 m deep), increasing water depth and distance from shore mean that burial disturbance remains longer due to reduced water movements and sediment supply, also bearing in mind that trenches in resistant sediments will persist longer than those in unconsolidated materials (NOAA, 2005). The exceptions are very narrow shelves, where river discharges can extend over much of the shelf, and the continental shelf edge, where tidal and other currents may intensify to actively move sediment. Thus similar principles apply: mobile sediments and associated faunas will recover more rapidly than counterparts in quiet, stable settings.

CABLE PLACEMENT AND ECOLOGICALLY SIGNIFICANT AREAS

The last 15 years have witnessed substantial advances in our knowledge and understanding of deep-ocean ecosystems. International research initiatives are revealing hitherto unknown or poorly known habitats and ecosystems (Ausubel, 1999; Freiwald *et al.*, 2004; UNEP, 2005, 2006). Currently under the spotlight are seamounts, cold-water coral communities, hydrothermal vents such as those found along the volcanic mid-ocean ridges, deep-ocean trenches, submarine canyons and the lower continental slope, amongst others.

Figure 5.6: Deep-water coral thicket on Chatham Rise, New Zealand. *Source: Dr M. Clark, National Institute of Water and Atmosphere (NIWA).*



To gain an insight into the nature, role and importance of these habitats and ecosystems, deep-sea or cold-water corals are instructive as they were recently the subject of a major review (Freiwald *et al.*, 2004). Located in water depths of 40–1,000 m or more, cold-water corals occur in all the major oceans. To date, most have been found in the North Atlantic – a feature that probably reflects the intensive research and exploration efforts in that region rather than it being a preferred habitat. While their full extent is unknown, recent studies suggest that the area occupied by cold-water corals may rival or exceed the coverage of tropical reefs. Off Norway alone, cold-water reefs cover c.2,000 km^2, and on Blake Plateau, southeast of the United States, an estimated 40,000 reefs may be present (Paull *et al.*, 2000). Compared to tropical coral reefs with their massive structures and multiple species composition (up to c.800), cold-water reefs are created by only a few species (c.6), and their so-called 'reef' structure is often in the form of dense thickets that develop on rocky outcrops, sediment mounds and even coral debris (Figure 5.6). Furthermore, they are slow growing, with rates of 4–25 mm per year compared to rates of up to 150 mm per year for tropical forms.

While a full appreciation and understanding of the ecological role of these 'reef' communities has yet to be realized, they are known to provide habitats and nursery grounds for fish and other marine organisms. As a result, reefs are targets for bottom trawl fishing that can cause substantial damage. In order to conserve cold-water corals and other potentially vulnerable deep-water habitats, many countries have created (or are in the process of establishing) protected areas or closures where trawls and other bottom-contact fishing gear are prohibited (Hourigan, 2008). When extensive trawl damage was documented for the Darwin Mounds off northwest Scotland (Masson *et al.*, 2002; Wheeler *et al.*, 2004), the European Commission imposed an emergency measure in 2003 and one year later permanently prohibited the use of bottom fishing trawls and gear on the Mounds and across 1,380 km^2 of the surrounding seabed. The Darwin Mounds are now designated as an offshore marine protected area, the first in the United Kingdom and part of a developing network that is planned to extend throughout the marine waters of the European Union. The need for more research and (in parallel) for more management and protection is also reflected in the recurring themes at International Deep-sea Coral Symposia (ISDCS, 2008). These included:

- improved identification and understanding of cold-water coral reefs and the need for nationally consistent management plans;
- recognition and accommodation of seabed users,

including implementation of effective policing of marine protected areas;

- management decisions and policy for corals, conservation and human impacts.

In general terms, these themes highlight the need to use and protect the marine environment sustainably, especially in international waters beyond the jurisdiction of coastal states. In the case of submarine cables, the United Nations Convention on the Law of the Sea (UNCLOS) prescribes the freedom to lay, maintain and repair cables outside territorial seas, but these are not necessarily inconsistent with the need to protect deep-ocean habitats and ecosystems, which is also reflected in UNCLOS:

- cable deployment in the deep ocean, i.e. laying of a 17–20 mm diameter tube on the surface of the ocean floor, has a minor if not negligible one-off impact;
- cable repairs can result in substrate disturbance. However, cable failures in deep water are relatively rare and are mainly caused by major natural events such as the 2006 Taiwan earthquake and submarine landslide (Introduction). Cable repairs resulting from human and natural agents in water depths greater than 1,200 m are c.5 per cent and c.7 per cent respectively of all repairs (Featherstone *et al.*, 2001; Kordahi and Shapiro, 2004).

In addition, the submarine cable industry, together with environmental regulators, attempts to reduce or avoid any impact on vulnerable deep-water ecosystems by:

- utilizing modern seabed mapping and navigation systems that allow identification of benthic habitats in unprecedented detail and accuracy (e.g. Masson *et al.*, 2002; Pickrill and Todd, 2003). Together with modern cable-laying techniques, it is now possible to deploy cables to avoid ecologically and biologically sensitive areas;
- avoiding the deployment of cables on or through habitats such as seamounts, submarine canyons and hydrothermal vents, which are also unsuitable as cable routes due to the risk of natural hazards (Chapter 6). For example, canyons are often swept by powerful currents that may abrade or break cables (Krause *et al.*, 1970; Shepherd and Marshall, 1969); seamounts can be volcanically active and subject to landslides and hydrothermal venting.

CABLE PROTECTION ZONES AND MARINE RESERVES

As coastal states increase protection of their submarine cable infrastructure, it has been mooted that designated cable protection zones may act as *de facto* marine reserves or sanctuaries (Froude and Smith, 2004). To gauge the reserve potential of such zones, a pilot study was made of exploitable fish species inside and outside the Southern Cross cable protection zone off New Zealand (Figure 5.7; Shears and Usmar, 2006). The authors found no statistical difference in species in or out of the zone, a result that was attributed to the short existence of the zone (four years) and illegal fishing. Furthermore, a zone must offer favourable habitats for marine species. In the case of the fish populations in or near the Southern Cross protection zone, fish preferred reef habitats rather than soft sediment substrates. Although results were inconclusive, the success of established marine reserves and sanctuaries suggests that cable protection zones with suitable habitats may help to maintain and improve biodiversity and species abundance, but this concept has yet to be proven.

Figure 5.7: Cable protection zone for the New Zealand terminal of the Southern Cross and other international submarine cables. Such protection zones have the potential to act as *de facto* marine reserves. *Source: Telecom New Zealand.*

6. Natural hazards

LEAVING THEIR MARK ON THE SEABED

The ocean encompasses a suite of dynamic environments that extend from the coast to the abyss. All are exposed to natural hazards, which are defined here as *naturally occurring physical phenomena caused by rapid- or slow-onset events, influenced by atmospheric, oceanic and geological forces that operate on timescales of hours to millennia* (modified from UNESCO, 2006). Such phenomena include weather-related disturbances, earthquakes, volcanic eruptions and, in the longer term, climate change. And all may directly or indirectly affect the safety of submarine cables.

The continental shelf and coast have a higher incidence of natural hazards due to the frequency of meteorological disturbances, as well as less frequent events such as tsunamis and earthquakes, all of which are overprinted on longer-term effects associated with tectonic and climatic change (e.g. Nittrouer, 1999; Gomez *et al*., 2004). As a result, coasts are exposed to flooding and erosion by surging seas and waves. The adjoining seabed may be scoured by currents and waves, or inundated by sediment as in the case of shelves fed by major rivers (Nittrouer *et al*., 2007). Some disturbances of the seabed can occur daily, as in tide-dominated settings (e.g. Carter and Lewis, 1995), or with the frequency of severe storms, which may strike once or more per year depending on the effects of climatic cycles such as the 3–8 year El Niño-Southern Oscillation or the 20–40 year Atlantic Multi-decadal Oscillation (NOAA, 2006).

The continental slope connects the shelf edge (average depth c.130 m) with the deep ocean at 1,000 m or more (Figure 6.1). Because of the slope's depth, the influence of storms is generally less than on the shelf. However, the slope is prone to gravitational forces. Sediment destabilized by earthquakes, tsunamis or severe storms moves down-slope as landslides that range from frequent small-volume (less than 1 km^3) displacements to rare giant slides of up to 20,000 km^3 (Figure 6.2; also Hampton *et al*., 1996; Collot *et al*., 2001). En route, slides may transform into more fluid debris flows or turbidity currents capable of travelling hundreds to thousands of kilometres (e.g. Krause *et al*., 1970; Piper *et al*., 1999).

Such catastrophic events leave their imprint in the form of landslide scars, zones of jumbled sediment masses, rough seabed topography (Figure 6.2) and, where turbidity currents are active, steep-sided submarine canyons. As well as down-slope movement of sediment, the continental slope acts as a boundary that guides currents and sediment along its flank.

The slope descends to the deep ocean – a nondescript term that belies a diversity of landforms and associated environments, including seamounts (many of which are

Figure 6.1: A generalized continental margin outlining the main depth-related zones and some of the processes that shape them. HST = high systems track deposited when sea level rises and encroaches shorewards; LST = low systems track when sea level lowers and retreats seaward. *Source: MARGINS Source to Sink Program, Lamont Doherty Geological Observatory.*

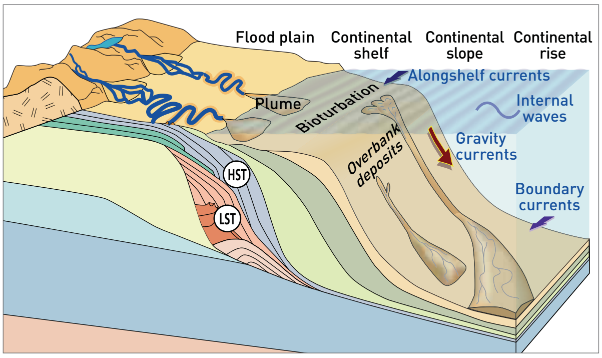
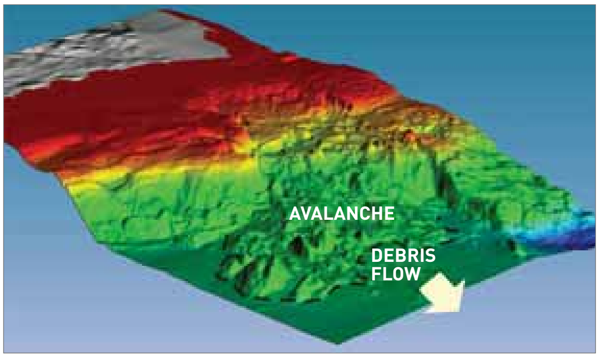


Figure 6.2: A giant submarine landslide (3,750 km^3 volume) comprising a blocky debris avalanche and a more fluid debris flow. This feature formed off New Zealand at the boundary between the colliding Pacific and Australian tectonic plates. *Source: Drs K. Lewis and G. Lamarche, NIWA.*



submarine volcanoes), mountain chains, plateaux, rises, fans and vast plains. There are also features that extend below the general ocean floor. Trenches, the deepest features on Earth, plunge several kilometres below the abyssal floor. Submarine channels may emanate from canyons incised into the continental slope, to wend their way across the ocean floor for distances sometimes exceeding 1,000 km. Each of these settings comes with its own hazards. Seamounts may be subject to volcanic activity that can form lava flows, hot-water vents, landslides and turbidity currents. Other steep-sided landforms may also be prone to landslides or erosion by currents that have intensified against marked topographic relief.

Contrary to the adage that 'still waters run deep', abyssal ocean currents can scour and transport sediment in water depths down to at least 6,000 m (Figure 6.3). Furthermore, these currents can be quite variable, with periods of steady flow punctuated by rapid turbulent pulses associated with the passage of large eddies. These are the aptly named 'abyssal storms' (Hollister and McCave, 1984).

As well as varying with depth, natural hazards differ with geography, reflecting Earth's wide range of geological, meteorological and climatic conditions. While storm-driven hazards are universal, their character and frequency are governed by local conditions. For instance, the very warm ocean temperatures of the Gulf of Mexico are a key factor contributing to the formation of hurricanes that sweep the region. Earthquakes and associated submarine landslides are also widespread, but they are most common where tectonic plates actively collide with one another, for example off Taiwan (Soh *et al.*, 2004) and New Zealand (Collot *et al.*, 2001), which are parts of the Pacific 'Ring of Fire'.

IMPACTS ON SUBMARINE CABLES

Between 65 and 75 per cent of all fibre-optic cable faults occur in water depths shallower than 200 m, and result mainly from fishing and shipping activities (Figure 6.4; Kordahi and Shapiro, 2004). By comparison, failures caused by natural hazards make up less than 10 per cent of all faults (Shapiro *et al.*, 1997). However, when focusing on deep-water cables, at least 31 per cent of faults can be traced to natural phenomena, with a further 14 per cent resulting from fish bites (Chapter 5) and 28 per cent attributed to unknown causes (Summers, 2001).

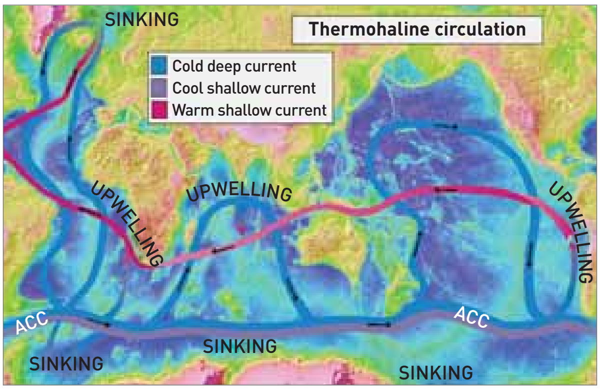


Figure 6.3: Outline of the thermohaline circulation, whose deep waters are driven by dense water sinking in the North Atlantic and Antarctica. The currents circulate around the main ocean basins before gradually returning to the surface and flowing northwards as warm surface currents under the influence of winds. The ACC is the Antarctic Circumpolar Current, which reinforces and modifies the thermohaline circulation in southern latitudes. *Source: B. Manighetti and NIWA.*

Storms strengthen current and wave action and hence increase their potential to affect cables on the continental shelf. Storm-forced movement of sand and gravel may abrade surface-laid cables (Carter, 1987) or cause suspensions in zones of moving sand waves (Allan, 2000) and on mixed substrates of rock and mobile sand. Cables laid on rock may respond to wave activity (Kogan *et al.*, 2006), resulting in abrasion, chafe and fatigue. Yet despite the dynamic nature of the continental shelf, cable failures caused by natural processes are (i) minor compared to those caused by human activities and (ii) apparently reducing in number (Kordahi and Shapiro, 2004). This decline probably relates to improved cable design, installation techniques and protection measures.

Figure 6.4: Types of cable faults recorded between 1959 and 2000. The data emphasize the dominance of faults caused by fishing and shipping activities, which typically cause damage in water depths shallower than 200 m. *Source: Wood and Carter (2008), IEEE Journal of Oceanic Engineering.*

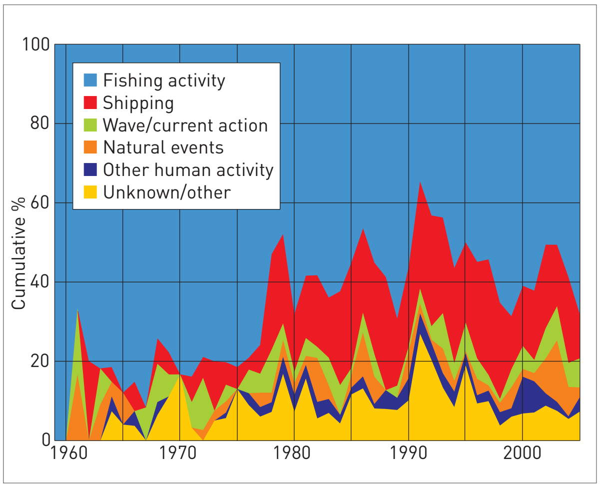


Figure 6.5: Typhoon Morakot struck Taiwan over 5–11 August 2009, when 3 m of rain fell in the central mountains, causing rivers to flood and carry large volumes of sediment to the ocean. So much sediment was discharged that several submarine landslides and associated sediment-laden 'turbidity currents' formed and broke a succession of cables off eastern and southern Taiwan as well as the nearby Philippines. While records of such events are insufficient to identify trends, the enhanced precipitation of Typhoon Morakot is consistent with warmer regional air and ocean temperatures. *Source: MODIS Rapid Response, NOAA.*

Cables can be damaged during hurricane, cyclone and typhoon attack (e.g. Cable and Wireless, 2004). However, most reports are from media sources that lack technical information on the precise nature and cause of cable damage. This was not the case for Hurricane Iwa (1982), whose impacts were recorded by ocean-current sensors on the continental slope off Oahu, Hawaii (Dengler *et al*., 1984). Current speeds of up to 200 cm/s (7.2 km/hr) were measured during the hurricane, and were followed by several submarine landslides which in turn transformed into the highly mobile turbidity currents. These moved down slope at 300 cm/s (11 km/hr) or more and damaged six cables. Subsequent repair and recovery operations revealed tensional cable breaks and abrasion. One cable section was unrecoverable, suggesting it was deeply buried by sediment carried down by landslides and/or turbidity currents. Most recently, the 2009 Typhoon Morakot generated sediment-laden flows that broke at least nine cables off Taiwan in water depths down to more than 4,000 m and over 300 km from the coastal area where the flows formed (Figure 6.5).

Earthquake-triggered landslides and turbidity currents are well-documented hazards. Since the classic study of Heezen and Ewing (1952), which recorded the severance of submarine cables by landslides and turbidity currents set off by the 1929 Grand Banks earthquake (Box 6.1), similar cases have been observed around the world, especially in earthquake-prone regions (e.g. Heezen and Ewing, 1952, 1955; Houtz and Wellman, 1962; Krause *et al*., 1970; Soh *et al*., 2004). Krause *et al*. (1970) also demonstrated the long distances and great depths covered by cable-damaging turbidity currents. In this instance, slides were triggered by an earthquake, probably near the Markham River delta off Papua New Guinea, and the resultant turbidity currents disrupted cables at least 280 km away in water depths of over 6,600 m. From the elapsed time between the earthquake and cable breaks, current speeds of 30–50 km/hr were derived. More recently, cables were damaged off (i) Algeria, following the 2003 Boumerdes earthquake (magnitude 6.8), when landslides and turbidity currents damaged six cables to disrupt all submarine networks in the Mediterranean region (Joseph and Hussong, 2003; Cattaneo *et al*., 2006) and (ii) southern Taiwan, in 2006, when nine cables broke under an earthquake-triggered flow (Renesys Corporation, 2007; Hsu *et al*., 2009) (Introduction).

Tsunami or seismic sea waves may disrupt services, especially at coasts susceptible to wave attack. Following the tsunami generated by the Andaman-Sumatra giant earthquake on 26 December 2004, land-based telecommunications networks were damaged in coastal Malaysia and South Africa, and there is one possible case of a submarine cable off South Africa being damaged by tsunami debris washed offshore (informal media sources; Strand and Masek, 2005).

Another cause of damage to cables is the formation of suspensions (Summers, 2001). As noted earlier, currents and waves on the continental shelf cause suspensions to sway, which may result in abrasion, chafe and fatigue. However, such effects also occur in the deep sea where cables traverse zones of strong flows. Off Iceland, for example, failure of the CANTAT-3 system has been attributed to cable movement in zones of rough topography during the passage of deep currents associated with the global thermohaline circulation (Figure 6.3; Malmberg, 2004). There, flows may reach maximum speeds of 31cm/s (1.1 km/hr) in water depths of 2,500–4,000 m.

Volcanic eruptions, like earthquakes, can trigger landslides and turbidity currents, but they also have their own brand of hazard associated with lava and volcanic debris flows. Yet despite the dramatic nature of eruptions, reports of associated cable damage are rare – a feature that may simply reflect an avoidance of submarine volcanoes by cable route planners. However, some habitable active volcanic islands, e.g. the Antilles and Hawaiian islands, rely on cables for communication. In May 1902, the eruptions of Mount Pelée, Martinique and La Soufrière, St Vincent, both in the Antilles Islands, were accompanied by a loss of submarine cable contact. The cause and location of the fault(s) are unknown, but Pararas-Carayannis (2006) speculates that the breakage may have resulted from a debris avalanche shaken from the sides of Mount Pelée.

CLIMATE CHANGE

In 2007, the Intergovernmental Panel on Climate Change provided projections of environmental responses to climate change through the 21st century (IPCC, 2007). The report, based on the peer-reviewed research of hundreds of scientists world-wide, is an exhaustive analysis of the world's climate – past, present and future. Since that report, new research has further refined or revised the earlier projections.

Some of the observed trends of relevance to submarine cables are as follows:

- Between 1961 and 2003, global average rise in sea level was 1.8 mm/yr, whereas from 1993 to the present the average rate is 3.1 mm/yr (University of Colorado, 2009; Chapter 8). Most sea level rise initially resulted from thermal expansion of the ocean, but more recent observations point to increasing contributions from the melting of ice sheets and glaciers (e.g. Steig *et al.*, 2009).
- The ocean has warmed to around 3,000 m depth. This vast store of heat will extend the effects of warming long after any stabilization of greenhouse gas emissions.
- The intensity of hurricanes appears to have increased since c.1970, but there is no clear trend in the numbers of these major wind storms.
- Changes have been observed in westerly wind belts, winter storm tracks, waves and weather-forced sea levels such as storm surges. These changes are projected to continue.
- Regional changes in precipitation are likely to occur and influence the flood delivery of river sediment to the continental shelf. The cable-damaging flood of Typhoon Morakot may be a harbinger of this projected trend.
- Ocean salinity (salt content) at middle to high latitudes has decreased due to increased precipitation and input of ice melt-water. This will alter the density of the upper ocean and its ability to sink and form deep currents, thus potentially affecting the global thermohaline circulation (Figure 6.3). Such a scenario is suggested by models, but is unsupported by observations, which reveal a strong natural variability in the circulation system that presently masks any long-term trends.

At present, we can only surmise any impact of climate change on submarine cables. Rising sea level may heighten the risk of erosion and flooding of coastal cable facilities, especially in regions subject to hurricanes and other intense storms. These will not only attack the coast, but also influence the stability of the continental shelf seabed via the formation of eroding currents and waves. As a result, cables laid on the seabed may be exposed to more abrasion or suspensions, although buried cables will be afforded some protection. More severe storms will increase the risk of submarine landslides and turbidity currents. A window into the future may be the disruption of the Southeast Asian cable network off Taiwan on 26 December 2006 (USGS, 2006; Hsu *et al.*, 2009). The already high river input of sediment to the ocean off Taiwan can increase three to fourfold when typhoons scour the landscape that has been destabilized by seismic and human activities (Dadson *et al.*, 2004; Webster *et al.*, 2005). As a result, thick deposits of mud and sand form on the seabed. These are ripe for disruption, as happened during 2006 (Hsu *et al.*, 2009). Regional changes in wind and rainfall will impact mainly on cables in coastal and shelf environments. For instance, increased windiness, as modelled for the middle latitudes of Oceania, may invigorate waves and ocean surface currents, thus increasing their capacity to shift seabed sediment. Large floods may

BOX 6.1: LEARNING FROM CABLE FAILURES

On 18 November 1929, a magnitude 7.2 earthquake shook the continental slope bordering the Grand Banks off Newfoundland. Submarine telegraph cables within c.100 km of the earthquake epicentre were cut instantly by a series of submarine landslides (Heezen and Ewing, 1952; Piper *et al.*, 1985, 1999). In turn, the slides formed a turbidity current that carried c.200 km^3 of sand and mud to water depths of at least 4,500 m (Nisbet and Piper, 1998). En route, the turbidity current broke more cables, but this time in sequence. From the timing of the breaks, a current speed of 65 km/hr was estimated. Although a disaster, the data it generated provided one of the first observations on how dynamic the deep ocean can be.

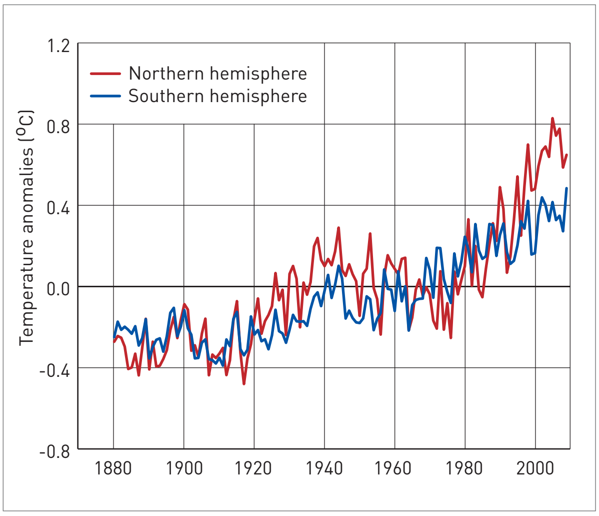


Figure 6.6: Observed temperatures for the northern and southern hemispheres, showing differences between the land-dominant north and ocean-dominant south, plus the strong temperature variability through time, which is superimposed on a long-term rising trend. *Source: Data from Goddard Institute for Space Studies, NASA.*

enhance siltation over cables or even form seabed-hugging mud flows with the potential to damage cables (e.g. Milliman and Kao, 2005).

It is important to appreciate that the ocean's reaction to global warming varies world-wide, reflecting the myriad of local and regional settings. For instance, most of the surface ocean has warmed in a patchy way by 0.1 to 1.0ºC, but some sectors of the mid-latitude southern hemisphere have cooled by -0.1 to -0.5ºC over the same period (NASA, 2006). This spatial variability is accompanied by strong variations over time. Natural cycles such as the El Niño-Southern Oscillation usually override long-term trends, but when these fluctuations are averaged out, the overall rise of temperature and sea level is readily apparent (Figure 6.6; Chapter 8). Thus, any evaluation of the potential effects of present global warming on cable systems must take into account local and regional conditions. An example is the North Atlantic, where the sinking of surface water as part of the global thermohaline circulation (Figure 6.3) lowers regional sea level by c.71 cm compared to the North Pacific (Hu *et al.*, 2009). Should the sinking of surface water slow or stop, this would cause a further rise in sea level on top of that caused by ice melting and thermal expansion.

7. Submarine cables and other maritime activities

INTRODUCTION

Every day, thousands of fishing vessels, merchant ships, oil rigs, dredgers, and recreational and research vessels ply the world's oceans. In most cases, their crews are unaware of the thousands of kilometres of submarine cables that lie on and under the seabed, carrying telephone calls and internet data that are a vital part of our world.

The cables, however, are sometimes affected by these activities. Every year, around 100–150 cases of cable damage are reported. Although some damage is from natural causes (Chapter 6), most is caused by humans (e.g. Shapiro *et al.*, 1997). When we consider the global scope and intensity of fishing, maritime transportation, hydrocarbon extraction, marine research, dredging and dumping, this is not surprising.

Although interaction between cables and human activities may seem inevitable, there are many reasons and ways to minimize it. A cable failure can cause severe disruption of international communications. In July 2005, such a break interrupted the majority of voice and data transmission into and out of Pakistan (Khan, 2005). Restoration of communications by satellite was insufficient to handle the traffic volume. The effects were felt by businesses, government and the general public of Pakistan for more than 10 days before the link was restored.

In some cases, if a vessel snags its fishing gear or anchor on a cable (Figure 7.1), vessel stability and crew safety can be affected. In spite of extensive warnings from cable companies, there are still occasional cases of fishermen hauling cables to the deck and cutting them, risking damage and injury not only from the weight and tension on the cable, but also from the electricity used to power the repeaters (Chapter 2).

Virtually every cable failure carries a high cost for restoration of service and repair, which must eventually be passed on to users of telecommunications services. Cable ships are kept on standby around the world, ready to respond at short notice, sail to the site of the damage and conduct repairs under all of the challenging conditions the ocean can offer (Lightwave, 2005; Sourcewire, 2000).

Fortunately, the cable sector and other mariners have found ways to cooperate and reduce cable damage. Virtually all of the ocean users capable of damaging cables also depend on the international communications they provide. This chapter explores the interactions between cables and other maritime activities, and the ways found to share the seabed in harmony and with respect.

CABLE DAMAGE

Cable damage comes in many forms. When damage is severe enough to affect transmission, it is considered a fault. One type of fault is a complete break, when a cable

Figure 7.1: Bottom trawler with trawl door (detail inset) snagging cable. *Source: ICPC Ltd.*

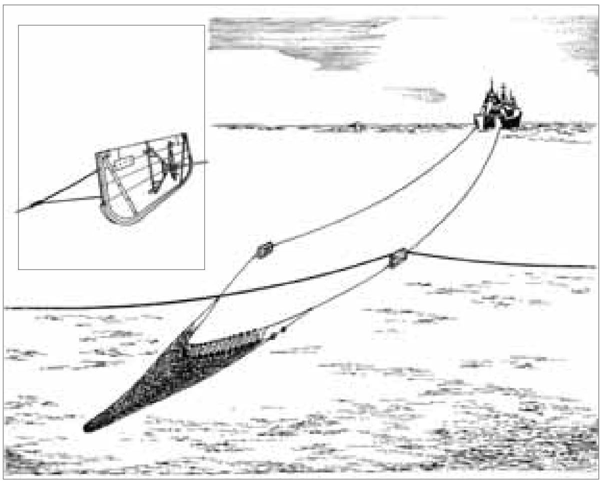


Figure 7.2: Cable damaged by fishing gear. A grapnel intended to retrieve fish traps from 1,800 m depth damaged the insulation and fibres on this cable. *Source: Tyco Telecommunications (US) Inc.*

Figure 7.3: Global pattern of external aggression cable faults, 1959–2006. *Source: Tyco Telecommunications (US) Inc.*

is pulled apart or severed. In such a case, the damage obviously affects both the optical fibres carrying communications and the copper conductor carrying the electrical current required to power the signal-boosting repeaters used on long-haul cable systems.

The modern submarine telecommunications cable has an outside diameter of c.17–50 mm, depending on the type of cable and armour (Chapter 2). The breaking strength of such cables ranges from a few tonnes to more than 40 tonnes for the double-armoured types. However, a cable may be rendered inoperable by forces smaller than those needed to sever it.

If a hard object in contact with a cable penetrates the armour and insulation to expose the copper conductor that carries electrical current (Figure 7.2), the usual result is that electrical current flows to the sea to form a shunt fault. In this case, the optical fibres may remain intact and capable of carrying signals, but the repeaters beyond the shunt may lack power and the cable may stop working. Sometimes, the voltage of the electrical power feed equipment at the ends of the cable can be balanced so that the repeaters on each side of the shunt continue to function, and the cable remains in service for a short time until a repair ship arrives. Shunt faults can result from fishing gear striking a cable or abrasion on the seabed, amongst a number of causes. In other cases, such as crushing, bending or pulling, the optical fibres themselves may be damaged. An optical fault results in loss of communication on one or more fibres. When a fishing trawl, anchor or other equipment snags or hooks a cable, it may exert enough force to pull the cable apart. Whatever the cause of the fault, it normally triggers an immediate alarm in the monitoring equipment, which runs constantly in the terminal stations on shore.

NUMBERS AND CAUSES OF CABLE FAULTS

The ICPC and several private organizations maintain records of cable faults. To date, there is no central global database of all fault records, so it is difficult to know exactly how many faults occur in a given year. However, based on records spanning several decades, it may be estimated that c.100–150 cable faults occur annually world-wide. Figure 7.3 indicates the distribution of faults caused by external forces (external aggression) including seabed movement and abrasion. These patterns were taken from a global database of 2,162 cable faults going back to 1959. It is clear that most faults occur on the continental shelf, near land in water depths of less than 100 m. This is to be expected, since the vast majority of human activities that involve seabed contact take place in relatively shallow waters. The remaining faults occur across a wide range of depths, including oceanic areas more than 4,000 m deep.

When a fault alarm sounds, in some cases an air or sea patrol is dispatched immediately to determine the cause. However, in most cases the cause must be investigated by other means. Fault causes are often grouped into the following categories: external human aggression, external natural aggression, component failure and unknown, e.g. Featherstone *et al.* (2001). External human aggression causes more faults than any other category, with fishing accounting for nearly half of all reported faults (Figure 7.4). Anchoring is the second major cause of faults, with dredging, drilling, seabed abrasion and earthquakes also causing significant numbers. However, natural hazards, including seabed abrasion, account for less than 10 per cent of all faults (Chapter 6).

Although cable systems are designed to last for at least 25 years, some components fail on rare occasions. In spite of harsh conditions of pressure and temperature, they have proved remarkably reliable, with some cables maintaining service for several decades. A recent analysis of fault causes found that less than 5 per cent of reported faults were caused by component failure (Kordahi and Shapiro, 2004). Moreover, component fault rates appear to have been falling in recent years, a fact not reflected in the summary chart (Figure 7.4), which includes data from the past five decades.

MARITIME ACTIVITIES AND CABLE FAULTS

To reduce interactions between cables and other maritime activities, some cable companies conduct extensive studies to understand these interactions. A focus on fishing is common since this is the greatest cause of damage. The goals are often to understand what areas are fished with which types of gear, and how deeply different types of gear penetrate the seabed. With this information, a cable company can more effectively plan cable routes, armouring and burial, and communicate with mariners engaged in the activities most likely to damage cables.

FISHING/CABLE INTERACTIONS

Bottom trawling

Bottom fishing is widespread on many of the continental shelves and adjacent continental slopes, and can extend to depths of c.1,500 m and more (e.g. Fishing News International, 1995; Freiwald *et al.*, 2004). Considering the thousands of fishing vessels working these shelves, and the hundreds of cables present, it is striking that interactions are relatively infrequent. Most fishing vessels never interact with cables, and many cables operate for years without faults. However, the 50–100 fishing faults experienced annually have substantial effects, disrupting communications and impacting costs (Drew and Hopper, 1996; Grosclaude, 2004).

Many different bottom fishing techniques interact with cables. This discussion will focus on the bottom trawl, because it is one of the most common types of commercial fishing gear and has a long history of cable interaction. A bottom otter trawl is a cone-shaped assembly of lines and netting that is dragged along the seabed behind a vessel (Figure 7.1). Trawl doors, also called otterboards, are steel (or steel and wooden) panels rigged ahead of the net on each side. They provide weight to keep the trawl in contact with the seabed and generate horizontal spreading force to keep the net mouth open. Otterboard weight may range from less than 100 kg per panel on the smallest trawlers to over 8 tonnes on the largest. The line along the bottom of the net is often rigged with chains, rollers, steel bobbins or rubber discs. This gear is designed to maintain contact with the seabed and stir the top few centimetres of sediment in order to capture fish and shellfish living on or just above the bottom. Estimated and observed values for seabed penetration of bottom trawls in sand and mud are typically in the range of 5–20 cm (Lokkeborg, 2005; Shapiro *et al.*, 1997; Stevenson *et al.*, 2003), but under unusual conditions such as very soft mud, uneven seabed or a rigging failure, a trawl door may dive 50 cm or more into the sediment for a short period. Fishermen try to avoid deep seabed penetration because it increases costs for fuel and gear damage without increasing catches. Rising fuel prices and pressure from the environmental community have contributed to recent trends toward development of gear with lighter seabed contact. It is worth noting that fishing gear snags on seabed obstacles are very common, and the vast majority do not involve cables.

Contact between cables and fishing gear

Several organizations have conducted extensive studies of trawl interactions with cables (Aitken, 1977; Drew and Hopper, 1996). Trawling is believed to be among the fishing methods that cause the most cable damage. This is partly

Figure 7.4: Proportion of cable faults by cause, from a database of 2,162 records spanning 1959–2006. *Source: Tyco Telecommunications (US) Inc.*

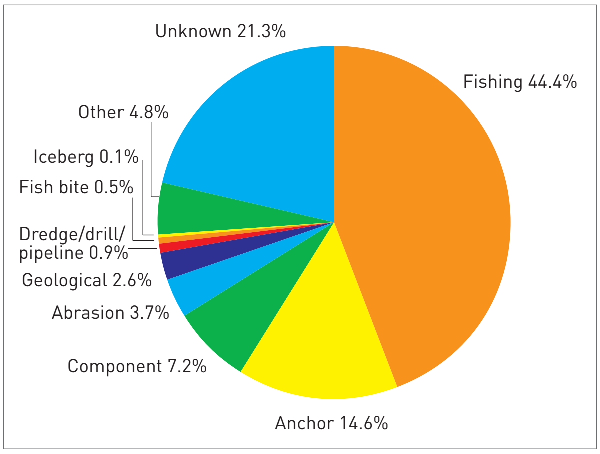


Figure 7.5: Fibre-optic cable with exterior sheathing recently damaged, presumably by fishing gear, to expose the bright steel armour, Cook Strait, New Zealand. *Source: Transpower New Zealand and Seaworks.*

because it is a widespread practice on most continental shelves, and partly because it is a mobile fishing method in which each operation may cover large areas of seabed (Lokkeborg, 2005). Research indicates that when a trawl crosses a communications cable lying on the seabed, more than 90 per cent of such crossings do not result in cable damage (Wilson, 2006). Trawls are designed to pass over seabed obstacles, and most cables in trawling depths are armoured. Cable burial and protective covers also provide greater protection and lower fault rates.

When a trawl passes over a submarine cable, a number of different outcomes are possible. As mentioned earlier, there may be no apparent contact at all. Many modern cables are buried more than 60 cm into the sediment from shore down to water depths of up to 1,500 m, so contact with normal fishing gear is highly unlikely. Even with cables lying on the bottom, trawl contact with the seabed may be light enough for the gear to pass over the cable with no discernible contact. Firmer contact may occur if a heavy trawl door, ground gear or even mid-water equipment lands on, or scrapes across, a cable lying on rocks or other hard bottom. During such contact, the armour may provide enough protection to avoid damage (Figure 7.5). Alternatively, a sharp corner of the fishing gear may penetrate the armour and insulation, causing a shunt fault, or bend or crush the glass fibres to cause an optical fault.

If a piece of fishing gear or anchor actually hooks or snags a cable, the likelihood of damage is far greater. Cable damage by bending, crushing and stretching can occur long before the cable breaks. This is one reason why cable companies discourage mariners from using anchors, grapnels or other equipment to drag for lost or unmarked gear near cables. In many areas, normal fishing gear may present almost no risk, but as soon as a grapnel is deployed to retrieve lost gear, the risk becomes extreme.

During installation in risk areas, every attempt is made to protect modern cables, either through burial into the seabed or by laying them flat on the seabed. Cable engineers constantly try to provide enough slack in a cable to let it conform to the seabed without leaving the cable loose enough for its inherent torsion to cause loops and kinks. This normally results in cables remaining in some permanent tension after installation. Consequently, in rocky or uneven seabed or on steep slopes, parts of a cable may be suspended above seabed depressions. If a piece of fishing gear contacts a suspension, a snag is more likely to result.

Cables can be more susceptible to damage in deeper waters. As water depth increases, cable burial generally becomes more difficult because of uneven seabed, steep slopes and the limitations of burial tools. Heavily armoured cable is harder to deploy in very deep water, so cables in deep water tend to carry less armour. A striking example of deep-water cable vulnerability is seen in interactions between cables and static fishing gear such as pots used for fish and shellfish. In shallow water, relatively few faults are believed to be caused by such static gear. Most shallow-water fish pots are light, and at these depths cables are armoured and generally buried. In deep water this situation is reversed – the static fishing gear is much heavier, often carrying large anchors, while the cables tend to have less armour and reduced burial depth. In some deep-water areas it also appears more common for fishermen to drag grapnels to retrieve static gear, and this greatly increases the risk. In recent years a number of faults have been caused by fishing activities using static gear in water depths of 500–1,800 m.

Fortunately for cables, most bottom fishing occurs in water depths of less than 100 m. The costs and risks associated with such fishing tend to increase with depth. With depletion of coastal resources, development of fishing technology and markets for new species, the 1980s and 1990s saw major increases in deep-water fishing (e.g. Pauly *et al.*, 2003). In a few areas, bottom trawling has extended to 1,500–1,800 m depths and bottom longline fishing with baited hooks may go even deeper. However, at such depths it appears that there are few areas with abundant fish populations of commercial value apart from those associated with elevated topography such as seamounts (Clark *et al.*, 2000). These features are routinely avoided in routing submarine cables, which may be a factor contributing to lower numbers of fishing and cable interactions in deeper waters.

During cable installation, there are rare instances of other types of interactions between cables and fishing gear suspended in the water column. In temperate and tropical oceans, fishermen catch tuna, swordfish and other species with mid-water longlines suspended from buoys. These longlines may range in length from a few hundred metres to over 100 kilometres (Beverly *et al.*, 2003), and they can be difficult to detect. If a lightweight cable is inadvertently laid over such a line, damage to both line and cable is likely. For this reason, cable companies generally try to notify all vessels in the area of cable installation, and clear the cable route before installation proceeds. In a similar fashion, faults have been caused by cables inadvertently installed over or near fish aggregating devices (FADs). A FAD is a buoy or raft, normally anchored, which serves to attract fish that live in mid-water or near the surface. Fishermen using this gear periodically visit it to fish with hooks or nets. Some FADs are identified by substantial marker buoys, but others are less conspicuous. If a lightweight cable is laid over the buoy line of a FAD, that line can easily chafe through the cable. Moreover, when the buoy line of a FAD parts, the anchored portion of that line may be difficult or impossible to retrieve. The abandoned buoyant line may remain suspended in the water column and present a long-term hazard to the installation of lightweight cables.

RISKS TO FISHERMEN AND VESSELS

When a cable is faulted, the cable company commonly receives no notice from the mariners involved and it is unclear whether those mariners are even aware of the interaction. In some cases the repair ship will find anchors or fishing gear snagged on the cable. Although many fishing and cable interactions appear to occur without negative effects on fishermen and vessels (and in some cases without their knowledge), there is danger associated with catching cables.

When gear fouls a cable, the gear may be damaged or lost completely. Any catches contained in nets are likely to be lost. If a fisherman tries to lift the cable to free his gear, the danger may increase. After an initial amount of slack is taken up, the load on the gear may rise dramatically, exceeding the capacity of the vessel's winches and causing damage. This can also affect a vessel's stability and, in extreme cases, risk capsizing. If fishermen succeed in bringing an active cable on deck, there is also a risk of electrocution (Figure 7.6).

OTHER CAUSES OF CABLE DAMAGE

After fishing activity, the most common cause of cable faults is vessel anchors. A 5,000-tonne vessel with a 4-tonne anchor may be expected to penetrate soft sediment to a depth of 5 m (Shapiro *et al.*, 1997). If such an anchor lands on a cable or drags and hooks a cable, a fault is likely. For smaller vessels, the pulling force on a snagged anchor may exceed the weight of the anchor by a wide margin. Such force may approach the breaking strength of the anchor line, the capacity of the anchor winch, or the buoyant force on a small vessel. Engineers avoid planning cable routes in or near charted anchorage areas, but vessels may also anchor in uncharted zones. Anchor faults tend to be most concentrated near busy ports, though on occasion they also occur over widespread areas.

Cable faults are occasionally caused by dredging associated with beach replenishment, sand or mineral extraction, etc. Other offshore activities such as petroleum extraction, pipeline construction, scientific research and dumping all lead to occasional cable breaks. Many of these may be avoided when the mariners involved consult charts showing cable routes, or request information from cable companies, but due to the intensity of marine activities (Figure 7.7) on a global scale there are still frequent faults.

MITIGATING FISHING AND CABLE INTERACTIONS

Over time, cable companies and other marine interests have found ways to mitigate their operational interactions. Careful planning of new cable routes is an essential first step. Charted anchorages and dredge areas are avoided. Maritime authorities and permitting processes may help. In many cases, industries such as fishing and merchant marine associations are consulted directly. These can often offer detailed information about local risks and potentially safer cable routes. However, despite cable planners' best and extensive efforts, it is not always possible to gather complete information on all uncharted areas where vessels may anchor, dredge, fish or conduct other activities.

Charts, notices to mariners and fishermen

If fishermen and other mariners are informed about the importance and locations of cables, in many cases they will

Figure 7.6: Beam trawler with gear snagged on cable (arrow). Snags cause trouble for fishermen, cable companies and users of communications services. *Source: Tyco Telecommunications (US) Inc.*

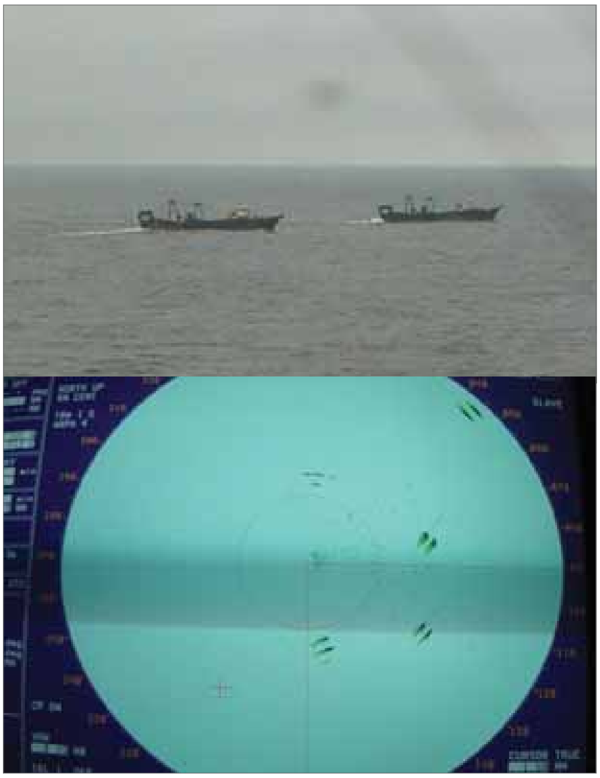


Figure 7.7: Pair trawlers observed and seen on the radar of a cable ship in the East China Sea. Avoiding and repairing cable faults can be difficult with this intensity of fishing effort. *Source: Tyco Telecommunications (US) Inc.*

take measures to avoid damage. An essential first step in informing mariners is publication in official notices to mariners and nautical charts, which are distributed by hydrographic and other authorities in various countries, e.g. ACMA (2007). However, there are limitations on this distribution system for some groups of mariners, e.g. coastal fishermen using small vessels who may not keep charts onboard. The period immediately after installation may also be difficult because distribution depends on the frequency of issue of the nautical charts and other notices in the local jurisdiction. In recent years, the trend towards electronic charts raises the possibility of more rapid publication of new cable information.

Many companies distribute additional information such as chartlets, brochures, leaflets or flyers showing cable routes and cable company contact information, highlighting the importance of avoiding damage to the communications infrastructure (e.g. Transpower and Ministry of Transport, 2008). This unofficial information distribution in some regions extends to distribution of electronic files for plotting cable routes on fishermen's navigation systems. It may begin before cable installation starts, depicting planned cable routes and advising mariners of upcoming installation activities. Representatives of cable companies sometimes attend fishermen's meetings and trade shows, or work through nautical suppliers to distribute such information.

Fishing and cable working groups

In some areas, the longstanding dialogue between cable companies and fishermen has been formalized into committees that exchange information and develop guidelines for recommended practices. These have developed new channels for information distribution, and in some cases developed guidelines for fishing more safely in areas where cables are present (OFCC, 2007; UKCPC, 2009). Among the issues they sometimes address is the use of 'cable-friendly' fishing gear – trawl doors and other gear built without sharp edges or notches that could snag cables. All parties have benefited from the understanding and working relationships that have developed from such groups.

8. The changing face of the deep: a glimpse into the future

The ocean is in a constant state of flux as it responds to a range of natural forces that operate on time scales of hours (weather) to millions of years (continental drift). But the ocean is now out of its 'comfort zone' as it faces unprecedented pressure from increasing human activities offshore and the effects of modern climate change (Halpern *et al.*, 2008; IPCC, 2007). Those pressures, along with a rapidly growing knowledge of the oceans, have fuelled a greater awareness of the marine environment and the problems it faces. This, in turn, has instigated efforts to conserve and protect marine resources, ecosystems and biodiversity (e.g. Freiwald *et al.*, 2004; Ministry of Fisheries, 2007). So what does the future hold, especially in the context of submarine telecommunications? Niels Bohr noted that 'Prediction is very difficult, especially about the future', but given the current state of the ocean (Halpern *et al.*, 2008), it is important to at least reflect on the future, guided by current trends and model simulations of change.

HUMAN ACTIVITIES

Fishing

As outlined previously, bottom trawl fisheries pose the greatest threat to submarine cables. During the 1980s, these fisheries extended into deep water in response to reduced stocks on the continental shelf (Smith, 2007b). Now, trawl fisheries can operate in water depths to 1,500 m and more, especially over submarine elevations such as seamounts and ridges. Future trends are unclear, but in some regions fishing effort and extent have waned due to:

- 'boom and bust' cycles, as illustrated by the orange roughy boom, when catches in the South Indian Ocean peaked at 39,000 tonnes for the year 2000, to be followed by a dramatic reduction to under 5,000 tonnes just two years later (Smith, 2007b);
- environmental degradation (Figure 8.1) coupled with declining fish stocks and by-catch issues, which have led to the closure of fishing areas and restrictions on gear type, e.g. areas off the United States are closed to protect benthic ecosystems (National Research Council, 2002; Pacific Fishery Management Council, 2005);
- the rising cost of fuel, which has been mooted as a market-driven control on energy-intensive deep-sea fisheries (Pauly *et al.*, 2003).

Figure 8.1: Trawl scars on the Chatham Rise, Southwest Pacific Ocean. *Source: Dr Malcolm Clark, NIWA.*

Any reduction in bottom trawl fishing should potentially lessen the threat to the cable network. However, actual benefits to the network will depend on the nature, timing and location of any reduced effort. For example, large areas of the exclusive economic zone off the western United States, including all areas deeper than 1,280 m (700 fathoms), have been closed to bottom trawl gear (Pacific Fishery Management Council, 2005). This legislative act could be expected to have an immediate benefit because the closure is regulated and takes in a major submarine cable route. In contrast, some regions could witness increased fishing effort as conservation and protection

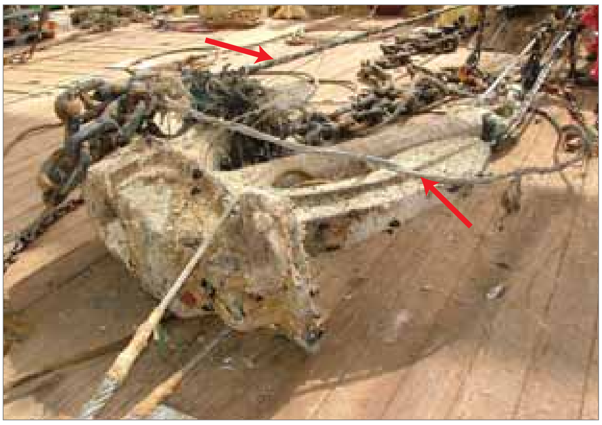


Figure 8.2: As the size and numbers of merchant vessels have increased, so has the risk of damage to submarine cables, as shown by a faulted cable (arrows) entangled with a ship's anchor. *Source: unknown.*

measures take effect and some fish species recover, e.g. NOAA (2009). Another fisheries development has been a fivefold growth in aquaculture, to a point where half the fish and shellfish consumed by humans now comes from farms, the remainder coming from fish caught in the wild (Naylor *et al.*, 2009). Continued growth of aquacultural farms is likely to add to the congestion of coastal seas.

Figure 8.3: The future is here: offshore wind farm, Kentish Flats, United Kingdom. *Source: ELSAM, Denmark.*

Shipping

After fishing, shipping activities, particularly anchoring (Figure 8.2), are the main threat to cable security. Over the last 12 years there has been a general increase in the number of ships and tonnage of the world merchant fleet (Institute of Shipping Economics and Logistics, 2005, 2007). In 2005, there were 39,932 vessels with a total tonnage of 880 million dwt (dead-weight tonnes). At the start of 2007, the fleet had grown to 42,872 ships with a total tonnage exceeding 1 billion dwt, the first time that threshold had been passed. Thus, merchant ships have become more numerous and, on average, heavier. In 2007, the fleet consisted of tankers (41 per cent), bulk carriers (36 per cent) and container ships (13 per cent), with the remainder being general cargo and passenger vessels.

Increased shipping may heighten the risk to the submarine network. Such an assessment needs to account for both those trade routes where vessel traffic has changed and the relationship of those routes to cable locations. A case in point is the rapid growth of the Chinese steel industry, which has been accompanied by growth in the bulk carrier fleet required to transport iron ore, mainly from Australia (40 per cent), India (28 per cent) and Brazil (19 per cent). Thus, cables on the continental shelves that are traversed by those shipping lanes are potentially exposed to more risk.

Renewable energy generation

Many countries are focusing on the generation of renewable energy as they seek to meet growing demand, establish secure supplies and reduce emissions of greenhouse gases. Wind farms, in particular, have become a familiar sight in coastal seas, especially off Europe (Figure 8.3). By comparison, wave- and current-powered systems are largely in the developmental stage, apart from scattered operational schemes such as the long-established La Rance tidal barrage in France (University of Strathclyde, 2002), a commercial wave generation plant installed off northern Portugal in 2006 (World Business Council for Sustainable Development, 2006) and current-driven turbines in the East River, New York, which deliver power to the local grid (Verdant Power, 2007). The outlook is for a significant expansion of offshore renewable energy schemes. Wind generation is projected to increase its operating capacity fourfold to 4.5 GW in the next five years (Douglas-Westwood, 2008). Most of this expansion will occur in Europe, where the United Kingdom is projected to replace Denmark as the leader in offshore wind generation through the proposed installation of large wind farms in the Thames Estuary (1,000 MW) and Bristol Channel (1,500 MW) (e.g. London Array, 2007).

Mineral and hydrocarbon exploitation

World oil and gas supplies are considered inadequate (Smith, 2007a), and a common thread through forecasts is that demand will surpass supplies of conventional oil in the next few decades (e.g. Bentley, 2002). To help address this imbalance, further exploration and production may come from offshore, and indeed growth in this sector is expected until at least 2011 (International Energy Agency, 2006). This growth may be linked to increased production from existing offshore fields and the discovery of new fields in deep waters beyond the continental shelf (Kelly, 1999). New hydrocarbon sources are also under investigation with the spotlight on sub-seabed deposits of gas hydrate – an ice-like form of methane found widely beneath the continental margin (Kennett *et al.*, 2003). These deposits have been researched at ocean and coastal sites, but as yet they have not been tapped commercially (e.g. Dallimore and Collett, 2005).

Offshore mining of non-hydrocarbon minerals is a long-established practice that typically has been dominated by the extraction of sand and gravel for aggregate (Glasby, 1982). Deposits bearing gold, tin, zircon, iron, titanium, phosphate and diamonds, amongst other minerals, have also been exploited. Considerable research has been devoted to polymetallic nodules which, along with manganese and iron, contain potentially economic concentrations of copper, nickel and cobalt. These widespread deep-ocean deposits have yet to be mined commercially. Nevertheless, with an eye on declining onshore mineral resources, several government agencies and companies have formally identified exploration and prospecting areas, especially in the central Pacific and Indian oceans. These large areas are mainly in international waters, meaning that any activity is regulated by the International Seabed Authority established in 1994 under the auspices of UNCLOS (International Seabed Authority, 2009).

Associated with offshore hydrocarbon production is the potential use of depleted oil and gas reservoirs to store carbon dioxide. Sequestration is currently under way in the Norwegian sector of the North Sea, where carbon dioxide from the Sleipner West hydrocarbon field is injected into a sandstone formation 1,000 m below the seabed (Figure 8.4; Statoil, 2004). In a recent analysis of available technologies to help reduce emissions of carbon dioxide, sub-seabed sequestration was a considered option (Pacala and Sokolow, 2005). However, in order to store 1 billion tonnes of carbon annually by 2054, the authors estimated that c.3,500 Sleipner-like fields would be required. If this option were implemented it could impact on cables through the development of new sequestering sites, re-establishment of abandoned oil and gas wells, and increased ship traffic or submarine pipelines to transfer captured carbon dioxide to the storage sites.

Figure 8.4: Sleipner West, the site of carbon dioxide storage in sub-seabed geological formations. *Source: Norsk Hydro.*

Ocean observatories

The last five years have been a period of growth for ocean observatories (ESONET, 2002; Joint Oceanographic Institutions, 2008; Ocean Sites, 2009). An internet-based survey reveals that the number of observatories has doubled since 2005. Presently, over 110 observatories are either operational or in development. Monitoring the ocean's interior, beyond the gaze of satellites, is a response to better identify its many environments, their living and non-living components, their functions, and their reactions to natural and human-related forces.

Observatories range from temporary, simple coastal moorings that measure a limited number of parameters such as water temperature, salinity (salt content) and current velocities to complex, permanent deep-ocean systems capable of taking a myriad of physical, biological, chemical and geophysical measurements, as well as conducting a range of experiments.

The most advanced of the large, permanent (20–25 year design life) observatories is the recently commissioned NEPTUNE system situated on the continental margin and adjacent deep-ocean floor off British Columbia, Canada (Figure 8.5; NEPTUNE, 2009). By 2008, 800 km of fibre-optic cable had been installed. This provides the communications and power to operate instruments and to transmit data back to Vancouver Island in real time, where it is made available to the scientific community and public. Several *nodes* were installed along the cable in 2009 (Figure 8.5). These car-sized units are akin to large junction boxes that receive plug-in sensors and other instrument packages. The great flexibility of this *plug-in-and-play* approach allows NEPTUNE to conduct experiments and monitor the wide range of environments extending from the upper ocean to below the seabed. The nodes, connecting cables and sensors are placed in areas that traditionally have been avoided by submarine telecommunications cables, including active hydrothermal vents, submarine volcanoes, areas of seismic risk and rugged ocean floor. In that context, such instrumentation needs to be located precisely in order to optimize its sensitivity, as well as to avoid any impact on the surrounding environment and other sensors nearby.

Climate change

The ocean is now responding to the present phase of climate change as outlined in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) and more recent research (e.g. Domingues *et al.*, 2008; Velicogna, 2009). Rising sea level, more intense storms, extremes of precipitation and drought, changes in the position and strength of zonal winds such as the Roaring Forties, together with effects on ocean currents, all have the potential to impinge directly on the cable network as outlined in Chapter 6. Some changes, such as rising sea level and changing weather patterns, are already under way and are likely to be with us for some time – a situation that has resulted from warming of the ocean interior (e.g. Gille, 2002; IPCC, 2007), creating a vast reservoir of heat that will continue to influence climate even if major reductions in greenhouse gas emissions are achieved.

A more specific analysis of potential hazards posed by climate change must account for its strong temporal variability. Sea level rise will vary depending on the site and local climate. In Auckland, New Zealand, sea level fluctuates in response to El Niño-La Niña cycles and the Interdecadal Pacific Oscillation (Goring and Bell, 1999). Despite such oscillations in that sea level record and others, an overall rising trend is unmistakable (Figure 8.6).

Similarly, the ocean's responses to warmer conditions will vary with location. If future El Niño phases become more intense, those cables off western-facing coasts in the Pacific region could be up against increased winds and storms which, together with rising sea level, have the potential to exacerbate wave and current erosion of the seabed and coast. In regions of high sediment input, such as the tectonically active Pacific Rim (Milliman and Syvitski, 1992), the combination of climate and tectonic activity has already taken its toll on submarine telecommunications. The destructive sub-sea landslide and turbidity currents that accompanied the 2006 Hengchun earthquake off Taiwan

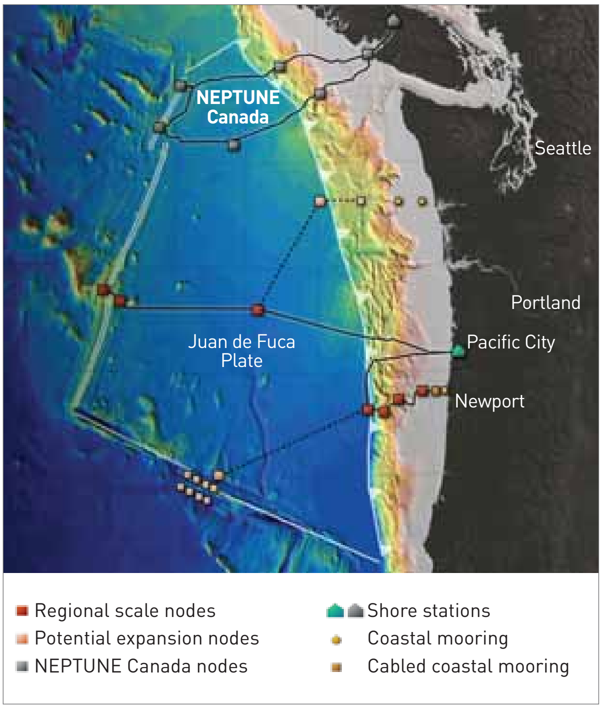
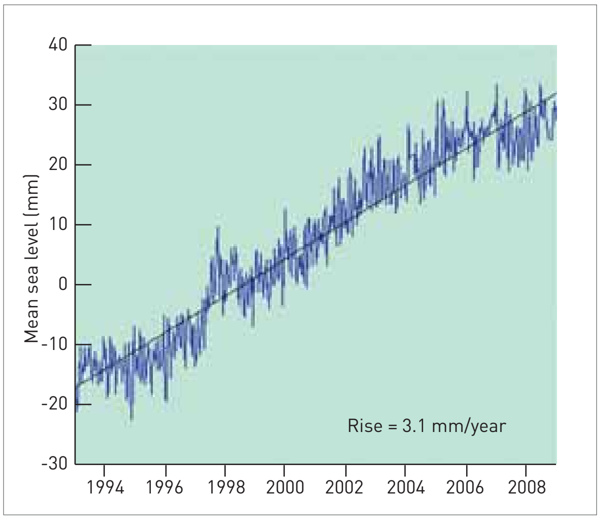


Figure 8.5: The recently installed NEPTUNE Canada cabled observatory with key monitoring and experimental sites or *nodes* (large grey squares). The proposed cabled observatory to the south is part of the US Ocean Observatories Initiative (OOI). *Source: Regional Scale Nodes and Center for Visualization, University of Washington.*

Figure 8.6: Despite variability in time and place, global mean sea level is on the rise in response to thermal expansion of the ocean coupled with increasing amounts of melt water from glaciers and polar ice sheets. *Source: Data from University of Colorado.*



were the result of a continuing tectonic-climatic cycle of earthquake destabilization of the terrestrial landscape (Dadson *et al.*, 2004), erosion of the landscape by storms and typhoons (Milliman and Kao, 2005) and the discharge of huge volumes of sediment to the ocean (Liu *et al.*, 2008), where thick deposits of sediment are formed and later destabilized by earthquakes to generate cable-damaging landslides and turbidity currents.

Marine protected areas

Awareness of human and natural stresses on the marine environment has led governments to promote and establish various types of marine protected areas (MPAs). One of the pioneers was Australia, which set up the Great Barrier Reef Marine Park in 1975 to provide environmental protection for the reef while allowing but regulating activities such as fishing, shipping and tourism (Australian Government, 2008; Doy, 2008). In Europe, the intergovernmental OSPAR Convention seeks to protect and sustainably manage a large sector of the Northeast Atlantic Ocean (OSPAR, 2009). At the national level, the United Kingdom continues to establish MPAs such as the Special Areas of Conservation (UK Marine Special Areas of Conservation, 2009). Likewise, the United States has afforded protection status to numerous areas off its mainland and island territories (Marine Protected Areas Center, 2009).

Most MPAs are located in coastal waters, but attention is turning further offshore, including international waters, in order to protect biodiversity and ecosystems such as cold-water coral communities. This was embodied in the recent European Union Marine Strategy Framework Directive (European Commission, 2008), which is aimed at protecting the European marine environment in concert with a desire to achieve the full economic potential of oceans and seas.

Activities such as ocean surveys can be restricted in MPAs, especially if intrusive methods are proposed. Even if a survey is possible, there can be restrictions placed on cable-laying activities. Thus, cable planners take due regard and, where possible, avoid areas that are designated as environmentally sensitive, e.g. warm-water coral reefs, cold-water coral communities and seagrass meadows. Knowledge of MPAs and sensitive benthic ecosystems is essential. Increasingly, information is appearing in the published literature and internet-based databases, which include maps of threatened and/or declining species and habitats, e.g. World Database on Marine Protected Areas (2009); Marine Protected Areas Center (2009); OSPAR (2009).

Ostensibly, any expansion of marine protected areas could be viewed as a further restriction on the passage of international cables. However, cables and marine protected areas may not be mutually exclusive. A surface-laid cable, beyond the depth of wave and current disturbance, has a minimum impact on the benthic environment (Figure 8.7; also Kogan *et al.*, 2006).

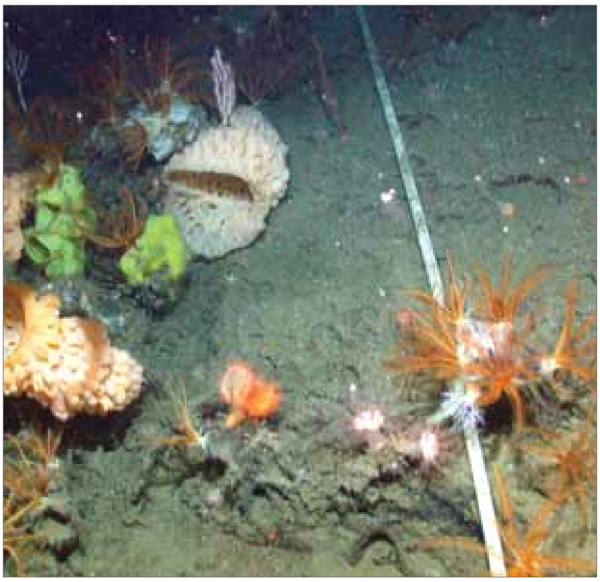


Figure 8.7: The ATOC scientific cable on Pioneer Seamount next to brightly coloured sponges, soft corals and feathery crinoids. *Source: 2003 Monterey Bay Aquarium and Research Institute (MBARI).*

Marine spatial planning

As our presence continues to grow offshore, governmental and non-governmental agencies seek to regulate this expansion through marine spatial planning (MSP) (Douvere and Ehler, 2008). In essence, MSP is a public process that aims to better organize human activities in marine areas to ultimately achieve ecological, economic and social objectives in an open and planned manner (Douvere and Ehler, 2009). Outside waters of national jurisdiction, however, there is no consensus on how such a system might work and what national or international legal regimes and institutions would be required for governance.

Two of several recurring themes for the establishment of successful MSP regimes are the need for good scientific information and the involvement of stakeholders. The exchange of information, mutual education and cooperation are essential for effective sharing of the seabed.

CONCLUDING COMMENTS

The submarine telecommunications network is an integral part of modern society. Since its establishment in the telegraph era, the network has extended around the planet. Historically, the highest communications traffic was between developed nations. However, that has changed. The network has rapidly expanded to connect most nations. East

African nations, for instance, are served by at least two major cable systems with more to follow within a year (e.g. EASSY, 2009; SEACOM, 2009). Southeast Asia is now a major telecommunications hub with the larger nations having substantial holdings in global cable companies. India is also a major cable owner and enjoys a high degree of connectivity, which in part reflects its position as a key centre for outsourcing services (Bardhan and Kroll, 2003).

The development of the fibre-optic highway as part of the world's *critical infrastructure* (Lacroix *et al.*, 2002) comes at a time of heightened awareness of the increasing pressures faced by the ocean. As outlined in this report, the weight of evidence shows that the environmental impact of fibre-optic cables is neutral to minor. In the deep ocean (more than c.1,000–1,500 m depth), which encompasses over 80 per cent of cable routes, any effect is limited to the placement of a non-toxic, 17–20 mm diameter tube on the ocean floor. The seabed may be disturbed periodically for repairs, but disturbance is localized and infrequent, as deep-ocean repairs account for less than 15 per cent of all cable faults (Kordahi and Shapiro, 2004). In the coastal ocean (less than c.1,000–1,500 m depth), fault repairs resulting from damage caused by fishing and anchoring, plus the need to bury cables for protection, disturb the seabed. However, studies cited in this report, including the OSPAR (2008) review on submarine *power* cables, conclude that disturbance is temporary, localized and infrequent.

As marine research continues to grow, it is highlighting hitherto poorly known benthic communities as well as discovering new ones. A prime example is cold-water coral communities, whose distribution, faunal composition and potential function have only recently come to light. By integrating such knowledge with that expressed in *Submarine Cables and the Oceans – Connecting the World,* the foundation is laid for a balanced approach to ocean use, its conservation and protection.

Glossary

Archipelago and archipelagic waters – an archipelago is a group of islands, including parts of islands, interconnecting waters and other natural features, which are so closely interrelated that they form a geographical, economic and political entity. In general terms, the associated archipelagic waters are those enclosed by a series of baselines that join the outermost points of the outermost islands in an archipelago. Such baselines are more specifically described under UNCLOS.

Armour – normally galvanized steel wires (of circular cross-section) laid around the core of the cable to provide both tensile strength and protection from external damage.

Atlantic Multidecadal Oscillation – a 20–40 year natural variability in the temperature of the North Atlantic Ocean surface, which may affect the formation of hurricanes.

Benthic community – an association of organisms living on, under or close to the ocean floor.

Bight – a U-shaped loop of cable or rope. Often refers to the single U-shaped loop of cable payed out from a cable ship as a final splice, or to the U-shaped loop of cable exiting the cable tank in which a repeater is positioned.

Biomass – the total mass of living material in a sample, population or specific area.

Biota – a collective term for the types of animals and plants present in a specific area or region at a given time.

Bottom otter trawl – a cone-shaped net attached by trawl lines to a fishing vessel and dragged across the ocean floor.

Branching unit (BU) – a sub-sea unit used at the point where a fibre-optic cable system splits into two legs, i.e. the fibres are split and may go to two terminals or to other branching units. Some branching units have the capability of switching the fibres from one leg to another.

Burial assessment survey (BAS) – a survey of the seabed to determine the likely success of any type of burial operation and to assist in the appropriate selection of cable armouring. Different combinations of tools may be used to constitute a BAS. For instance, it may be invasive and continuous, such as a mini-plough or grapnel-shaped tool. Alternatively, sampling can be carried out at discrete sites using techniques such as cone penetrometer tests (CPTs), or by sediment coring. Geophysical methods, such as resistivity or seismic reflection, can be used, or any combination of the above.

Cable network – a regional to global grouping of interconnected submarine cables, including repeaters and landing stations. A network provides redundancy in the event of a cable failure, in which instance voice and data traffic can be re-routed via intact parts of the network.

Cable protection zone – a defined area, usually identified on official marine charts, where submarine cables are afforded legal protection supported by various policing measures. Cable protection zones extending beyond territorial seas, normally 12 nautical miles, are generally not recognized under international law.

Cable route survey – a marine survey operation to obtain all the necessary information to design and engineer a cost-effective and reliable submarine cable system. Following receipt of the survey report, the installation cable route is optimized on the basis of data obtained on the seabed bathymetry (depth contours etc.), character, sediment thickness, marine life and other useful information such as currents, temperatures and prevailing weather conditions. The survey determines whether cable burial is required or indeed possible. A cable route survey is a prerequisite to laying a submarine cable and is integral to the freedom to lay and maintain international submarine cables under UNCLOS.

Cable vessel (also cable ship) – a vessel purpose-built or modified to lay and repair submarine cables. When engaged in such operations, the cable vessel displays special insignia or 'shapes' and navigation lights to alert other vessels to its restricted manoeuvrability as required by international law.

Census of Marine Life (COML) – a global network of researchers, representing more than 80 nations, engaged in a 10-year assessment and interpretation of the diversity, distribution and abundance of life in the oceans. The world's first comprehensive census is scheduled for release in 2010.

Climate change – a change in the state of the climate that can be identified by changes in the mean and/or variability of climatic properties (e.g. temperature, rainfall, wind) that persist for decades or longer.

Cold-water corals – a group of benthic anthozoans, commonly with a skeleton of calcium carbonate, which exist as individuals or form colonies. Unlike tropical corals, cold-water corals have no light-dependent algae and inhabit water depths to over 1,000 m in water temperatures of 4–13ºC.

Component failure – whereby a constituent part of a cable fails and produces a fault. Failures of this type account for c.7 per cent of all cable faults.

Continental shelf – a zone, adjacent to a continent or island, which extends from the coast as a gently sloping plain (c.0.1º) to the shelf edge, where the seabed steepens to form the continental slope. The average depth of the shelf edge is c.135 m. The precise limits of a nation's legal continental shelf boundary claim beyond the EEZ are determined in accordance with criteria set forth in UNCLOS, but in no case shall extend beyond 350 nautical miles from the coastal state's coastal baseline.

Continental slope – a zone of relatively steep seabed (c.3-6º), extending from the shelf edge to the deep ocean. The slope is often incised by submarine canyons and/or landslides.

Convention on Biological Diversity – a convention established in 1993 to conserve biological biodiversity, to ensure the sustainable use of its components, and to share the benefits arising from utilization of genetic resources.

Deep-ocean trench – a long, narrow, steep-sided depression of the ocean floor that includes the deepest parts of the ocean.

Desktop study – a review of published and unpublished information which, in the context of submarine cables, provides an initial assessment of engineering, environmental and legal factors relating to a cable route.

El Niño-Southern Oscillation (ENSO) – describes regional changes in the atmosphere and ocean in the equatorial Pacific that occur on a c.3–7 year cycle.

Environmental impact assessment (EIA) – an evaluation of the potential environmental implications of laying and maintaining a submarine cable. An EIA may be required as part of the permission process for cable installation.

Epifauna – animals that live on surfaces such as the seabed, other organisms and objects including cables.

Epiflora – plants that reside on a surface such as the seabed, other organisms and objects including cables.

Exclusive economic zone (EEZ) – an area beyond and adjacent to the territorial sea that is subject to the specific legal regime established under UNCLOS. The EEZ extends to a maximum of 200 nautical miles from a coastal state's coastal baseline.

External human aggression fault – a cable fault caused by an external force, in this case by human activities such as fishing, anchoring, dredging, drilling etc.

External natural aggression fault – a cable fault caused by external natural forces such as submarine landslides and turbidity currents triggered by earthquakes.

Fish aggregating device (FAD) – various types of artificial float, either drifting or anchored to the seabed, designed to attract pelagic (mid-water-dwelling) fish including tuna and marlin.

Gas hydrate – an ice-like solid formed from a mixture of water and natural gas, usually methane, found in marine sediments. Hydrates are a potential source of hydrocarbon-based energy.

Global positioning system (GPS) – a global navigation system designed to provide accurate positional and navigational information derived from a constellation of 24 to 32 satellites.

Grapnel – a specialized hooked device used to recover submarine cables for repair or removal. Smaller grapnels are used by some fishermen to recover lost fishing gear.

Gutta percha – a natural gum from trees found on the Malay Peninsula and elsewhere; used to insulate submarine cables until the 1930s, when it was replaced by more durable plastics.

High seas – open ocean that is not within the territorial waters or jurisdiction of any particular state. The high seas are open to all states, whether coastal or land-locked. Freedoms of the high seas are exercised under the conditions laid down by UNCLOS and other rules of international law.

Hydrography – the science of measurement of physical aspects of Earth's surface waters, including water properties, flow and boundaries.

Hydrothermal vents – include fissures and fractures from which hot, often mineral-rich waters are expelled, especially along mid-ocean ridges and hotspots. Waters can reach +350ºC, but rapidly cool in the cold ocean, forcing the precipitation of minerals.

Intergovernmental Panel on Climate Change – a science-based panel, set up in 1988 by the World Meteorological Organization and the United Nations Environment Programme, to evaluate the effects and risks of human-influenced climate change.

Internal waves – gravity waves that oscillate within a medium, in contrast to waves that form on the ocean surface. Internal waves may propagate along zones of marked density contrast in the ocean without disturbing the sea surface.

International Tribunal for the Law of the Sea (ITLOS) – an independent judicial body, located in Hamburg, Federal Republic of Germany, established under UNCLOS, to adjudicate disputes arising out of the interpretation and application of the Convention.

Marine protected area – a formally designated area of open or coastal ocean whose natural and cultural resources are protected and managed by legal or other effective means.

Mid-ocean ridges – continuous mountain ranges that have formed along the central reaches of the main oceans. They mark the zones where tectonic plates drift apart to allow magma to upwell and form new volcanic crust/seafloor.

Multibeam systems – a ship-based or towed acoustic mapping system that allows swaths of seabed, up to tens of kilometres wide depending on water depth, to be accurately mapped during a single survey run.

Natural hazard – a naturally occurring physical phenomenon caused by rapid- or slow-onset events under the influence of atmospheric, oceanic or geological forces operating on time scales of hours to millennia.

Notice to mariners – published notifications that advise of changes in navigational aids, new hazards such as shipwrecks, new offshore installations, changes in water depth, submarine cable locations and operations, and other matters. This procedure allows for the constant updating of navigational charts.

Ocean observatories – semi-permanent or permanent observation sites in the ocean, designed to monitor a wide range of environmental parameters. Observatories have many configurations depending on the type of experiments and monitoring to be conducted. The data generated may be recovered by ships, satellite or, in the latest observatories, via submarine fibre-optic cable for transmission to shore-based facilities.

Optical amplifier – uses special fibres and a laser pump to amplify an optical signal. This is done without the optical signal being regenerated by conversion to an electrical signal and converted back into an optical signal (as is the case with optical regenerators). Submarine optical amplifiers are packaged in housings in a manner similar to repeaters and continue to be referred to as repeaters.

Optical fault – a fault caused by damage to the glass optical fibres in a submarine cable.

Otterboards – (also called trawl doors) typically heavy rectangular, oval or curved plates of metal or wood connected by the trawl lines to a fishing vessel and designed to keep the mouth of the net open.

Plough burial – burial of the cable into the seabed for enhanced cable protection. The cable is guided into a self-closing furrow cut by a sea plough towed by a cable ship.

Post-lay inspection (PLI) – an inspection conducted after deployment of a cable on or into the seabed to ensure correct placement and to monitor any subsequent environmental effects.

Post-lay inspection and burial (PLIB) – an operation usually carried out by an ROV in areas of plough burial after the cable installation. The inspection operation confirms the burial depth. If necessary, additional burial (usually by jetting) can be implemented in localized areas, e.g. at 'plough skips' where the plough has been recovered for repair or maintenance.

Remotely operated vehicle (ROV) – an unmanned submersible vehicle used to inspect, bury or exhume cables. They can also be used, *inter alia*, to carry out surveys and inspection of the cable on the seabed. ROVs are usually fitted with cameras and cable tracking equipment, and for burial operations can be fitted with jetting or trenching tools. ROVs are controlled from surface vessels and operate mainly in waters shallower than c.2,000 m.

Renewable energy farms – an integrated suite of devices that generate energy from ocean winds, waves, currents or tides and transfer the electricity to shore via submarine power cables.

Repeater – a submerged housing containing equipment that boosts the telecommunications signal at regular intervals along the cable (Figure 2.5). Each repeater is powered via an electrical current that is fed into the submarine cable system from the shore-based terminal stations. All telecommunications signals lose strength in proportion to the distance travelled, which explains why repeaters are only required on the longer submarine cable routes. The term 'repeater' originated in the telegraph era and has continued in use as a generic term to describe the submerged signal-boosting equipment that has been required in all of the longer submarine cable systems, regardless of the transmission technology used. In a modern fibre-optic submarine cable system, the repeater spacing is typically 70 km.

Sand waves – a condition where the seabed is covered by sand waves whose movement may expose previously buried cable.

Seamount – submarine elevation with the form of a mountain whose size differentiates it from small elevations such as pinnacles, banks and knolls.

Sea plough – see *Plough burial*

Sediment, marine – solid fragmental material, ranging in size from clay particles to boulders, derived from terrestrial or marine sources and distributed by water, wind or ice.

Seismic profiler – see *Sub-bottom profiler*

Shunt fault – occurs when a cable's insulation is damaged or degraded. This exposes the copper conductor carrying electrical current, which passes or 'shorts' into the ocean.

Side-scan sonar – an acoustic technique to map the reflectivity of seabed material to identify potential obstructions on the seabed. Used primarily during surveys prior to ploughing operations. The use of side-scan sonar is helpful in cable repair operations in identifying surface-laid cables and in localizing fault locations.

Strumming – a term used to describe the standing wave vibration set up in unsupported cable during deployment or when in suspension between localized high sectors on the seabed. Strumming is induced by the drag forces generated when water currents flow across the cable in suspension.

Sub-bottom profiler (SBP) – an acoustic method of determining the vertical geological structure of the upper seabed. SBP equipment releases low-power, high-frequency, short pulses of acoustic energy into the water column and measures energy reflected back from the seabed and from layers below the seabed, revealing the differing physical properties of those layers. For cables, this information helps define potential hazards and the availability of sediment suitable for cable burial.

Submarine canyon – a narrow, steep-sided, V-shaped depression, typically incised into the continental shelf and slope.

Submarine channel – a shallow to steep-sided depression that may be fed by one or more submarine canyons. Compared to canyons, channels usually have V- to U-shaped profiles, are often bordered by well-developed levee systems, are longer and extend to greater ocean depths.

Submarine coaxial cable – a telephonic communications system comprising inner and outer copper conductors separated by a polyethylene insulator. This design replaced telegraphic cables in the 1950s, and was later replaced by fibre-optic designs.

Submarine fibre-optic cable – a communications system in which digitized data and voice signals are converted to coded light pulses and transmitted along optical glass fibres. Fibre-optic cables replaced coaxial cables in the 1980s.

Submarine landslides – a general term that encompasses mainly gravity-driven, downward and outward movements of sediment and rock. They frequently occur on, but are not confined to, continental slopes, especially those in seismically active regions.

Submarine telegraphic cable – an earlier communications system in which coded electrical impulses were transmitted through an insulated copper wire conductor.

Submarine telephone cable – see *Submarine coaxial cable*

Suspension – a term used to describe an unsupported length of cable held in a catenary by the residual cable tension at each side of the suspension. Suspended cables can suffer damage at the contact points where abrasion (chafe) can occur and may be subject to strumming.

Tectonic plate – a large, relatively rigid segment of the Earth's crust and upper mantle that moves horizontally and interacts with other plates to produce seismic, volcanic and tectonic activity.

Territorial sea – refers to a state's coastal waters, which extend out to 12 nautical miles from a baseline commonly defined by the mean low water mark. Territorial sea limits and permitted activities in territorial seas are determined in accordance with UNCLOS and international law.

Thermohaline circulation – a world-wide, interconnected system of currents, which are driven mainly by density differences associated with atmospheric cooling or heating of the ocean and the addition or loss of fresh water. Winds also play a prominent role in driving the circulation.

Tsunami – waves of great wavelength, usually generated by earthquakes or submarine landslides; not to be confused with 'tidal waves', which result from astronomical forces on the ocean.

Turbidity current – a dense, sediment-laden current that flows rapidly across the ocean floor, often via submarine canyons and channels. Turbidity currents can be triggered by earthquakes, storms and river floods, and are capable of breaking submarine cables.

United Nations Convention on the Law of the Sea (UNCLOS), 1982 – a convention known as the 'constitution of the world's oceans' that entered into force in 1994. UNCLOS establishes a legal framework to govern all ocean space, its uses and resources. It contains provisions relating to the territorial sea, the contiguous zone, the legal continental shelf, the exclusive economic zone and the high seas. UNCLOS defines freedoms and responsibilities for international submarine cables, navigation and other activities within these zones. It also provides for environmental protection and preservation, marine scientific research, and the development and transfer of marine technology.

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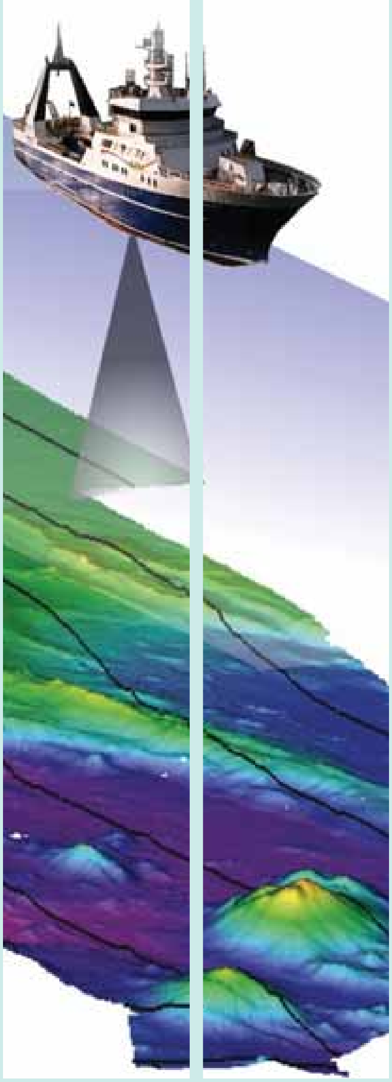

Submarine cables and the oceans: connecting the world

The first submarine cable – a copper-based telegraph cable – was laid across the Channel between the United Kingdom and France in 1850. Since then, submarine cables have literally connected the world. Now, when clicking the 'Send' button on an intercontinental email, it will almost certainly travel via the global network of submarine fibre-optic cables. The establishment of this network over the past two decades, together with the rapid rise of the internet, has revolutionized communications. The significance of that revolution was underscored in 2009 when the pioneer of fibre-optic communications, Professor Charles K. Kao, shared the Nobel Prize for Physics. Today, financial markets, general commerce, education, entertainment or just a simple telephone call are almost totally dependent on the submarine cable network whenever a trans-oceanic connection is required.

The last 20 years have also witnessed a greater human presence in coastal seas and oceans as a growing population seeks more space and resources. Coastal seas in Europe now accommodate wind turbine farms as nations develop clean and secure supplies of renewable energy. Large areas of the deep Pacific and Indian oceans have been marked for future mineral exploration. Even traditional uses of the oceans, such as fishing and shipping, are changing. The number and size of merchant ships have increased, in part to service the rapidly expanding economies of China and India. Aquaculture now accounts for 50 per cent of the fish for human consumption, with the remainder coming from traditional wild fisheries. This ever-increasing human presence offshore has not gone unnoticed. Governments and other organizations are seeking to conserve and protect the marine environment, while mindful that such measures need to be balanced with responsible development in order to meet human needs.

In that context, *Submarine Cables and the Oceans – Connecting the World* is a timely account of an historic use of the oceans, namely as a seabed platform for the submarine telecommunications cable network. This report covers the history and nature of cables, their special status in international law, their interaction with the environment and other ocean users and, finally, the challenges of the future. It is an evidence-based synopsis that aims to improve the quality and availability of information to enhance understanding and cooperation between all stakeholders.

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