Chapter 2 • The life cycle of Fraser River sockeye salmon

Introduction

In this chapter, I summarize the extraordinary life cycle of the Fraser River sockeye salmon to provide the reader with some context for my later discussion of fisheries management issues and possible causes of the recent decline. I have drawn from several sources, including both the concise summary of the life cycle in the Commission's Technical Report 4, Marine Ecology,[1] and the testimony of three witnesses: Michael Lapointe (chief biologist with the Pacific Salmon Commission), Dr. David Welch (president of Kintama Research Services Ltd.), and Karl English (senior fisheries scientist with LGL Limited environmental research associates).*

From the headwaters in the Rocky Mountains, the Fraser River follows the Rocky Mountain Trench to the Interior Plateau. It continues south to the Coast Mountains and drains from a broad flood plain into the Strait of Georgia. Within the Fraser River watershed there are hundreds of tributaries, streams, marshes, bogs, swamps, sloughs, and lakes. The river is 1,600 km long, with a watershed size of 223,000 km^2 and a lake nursery area of 2,500 km^2.

The Fraser River supports the largest abundance of sockeye salmon in the world for a single river. More than 50 percent of all salmon production in British Columbia occurs in the Fraser River watershed.[2]

Figure 1.2.1 provides a month-by-month timeline of the Fraser River sockeye salmon life cycle.

* See also Exhibits 1, 2, and 3, respectively, for slide presentations prepared by the three witnesses.

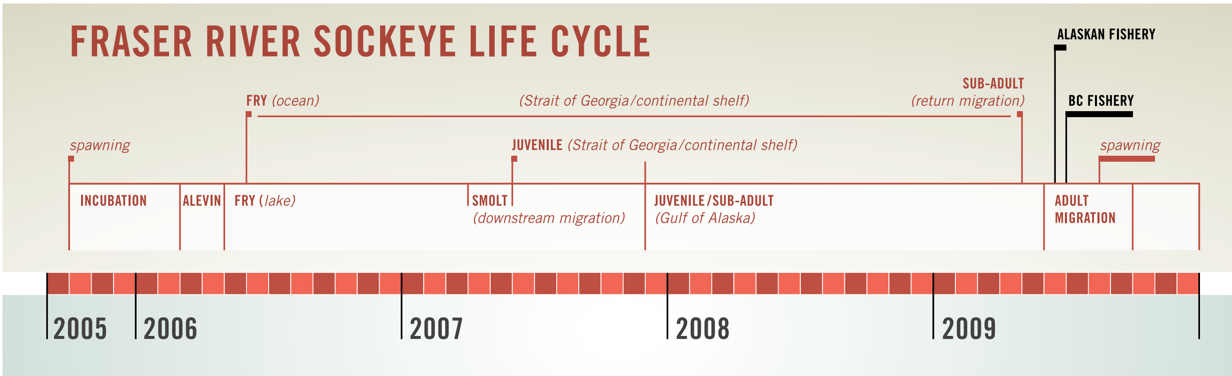

Figure 1.2.1 Fraser River sockeye salmon life cycle

Note: This figure reflects an average four-year life cycle. Variations will be found within each stock; however, some fish return at three years of age and others at five years of age. In addition, this figure does not reflect the unique life cycle of the Harrison River stock.
Source: Cohen Commission of Inquiry.

A typical life cycle

Fraser River sockeye salmon generally have a four-year lifespan. The following examination considers 2009 spawners as an example. Their life began in the fall of 2005, when their parents returned to their natal streams throughout the Fraser River watershed to spawn.

Spawning

During the spawning process, the female is the dominant partner and interacts with both the gravel environment and the courting male in a specific sequence of activities. The activities include nest site selection, nest construction, courtship display, release of eggs, fertilization, covering of the nest, and defending against intruders. The female selects a site for the deposit of her eggs (“redd”); digs a depression (“nest”) in the gravel substrate; and deposits 500 to 1,100 eggs, which are simultaneously fertilized by an accompanying male or males. She then covers the eggs by further digging and repeats the digging and spawning process up to several times. Finally she covers the completed redd, which may contain several nests of eggs, and then guards the site until near death. A few days after she has completed spawning, she dies. Her body floats away with the current or sinks to the bottom, creating room on the spawning grounds for the next wave of ripe females to occupy nesting territories. The whole spawning process, from moving onto the spawning grounds to death, lasts about 10 days. Each spawning female lays between 3,000 and 4,000 eggs in the gravel, the number of eggs depending on the female’s body size. Fish spawning in fine substrate tend to produce smaller eggs than fish spawning in very coarse substrate.

Eggs

During the winter, salmon eggs develop in the gravel, where they are protected from floods, ice conditions, and predators. The rate of egg development during incubation depends on water temperature and genetic characteristics related to environmental conditions of the specific population. Embryonic development is faster as the temperature increases; a small difference in average incubation temperature can change emergence timing by four weeks.[3]

Alevins

In the early spring, after about five months’ incubation, alevins emerge from the eggs. A pronounced yolk sac suspended below the body provides nourishment for six to 10 weeks, depending on water temperature. During this period, the alevins remain in the gravel for protection from predators and because they are poor swimmers.

Mr. Lapointe explained that there are several sources of egg and alevin mortality, including predation by birds and fish, being dug up by later-spawning females, desiccation (dehydration) and freezing resulting from low water levels, physical disturbance (e.g., scouring of nesting areas because of high water flows), suffocation caused by fine sediment or low oxygen, and diseases and parasites.[4]

Fry

In about May 2006, approximately eight months after spawning, the yolk sac is absorbed into the body cavity, and the alevins become fry. The fry, now typically about 3 cm long, migrate downstream (or, more rarely, upstream) into a nursery lake in search of food. The distribution of Fraser River sockeye salmon nursery lakes is shown in Figure 1.2.2.

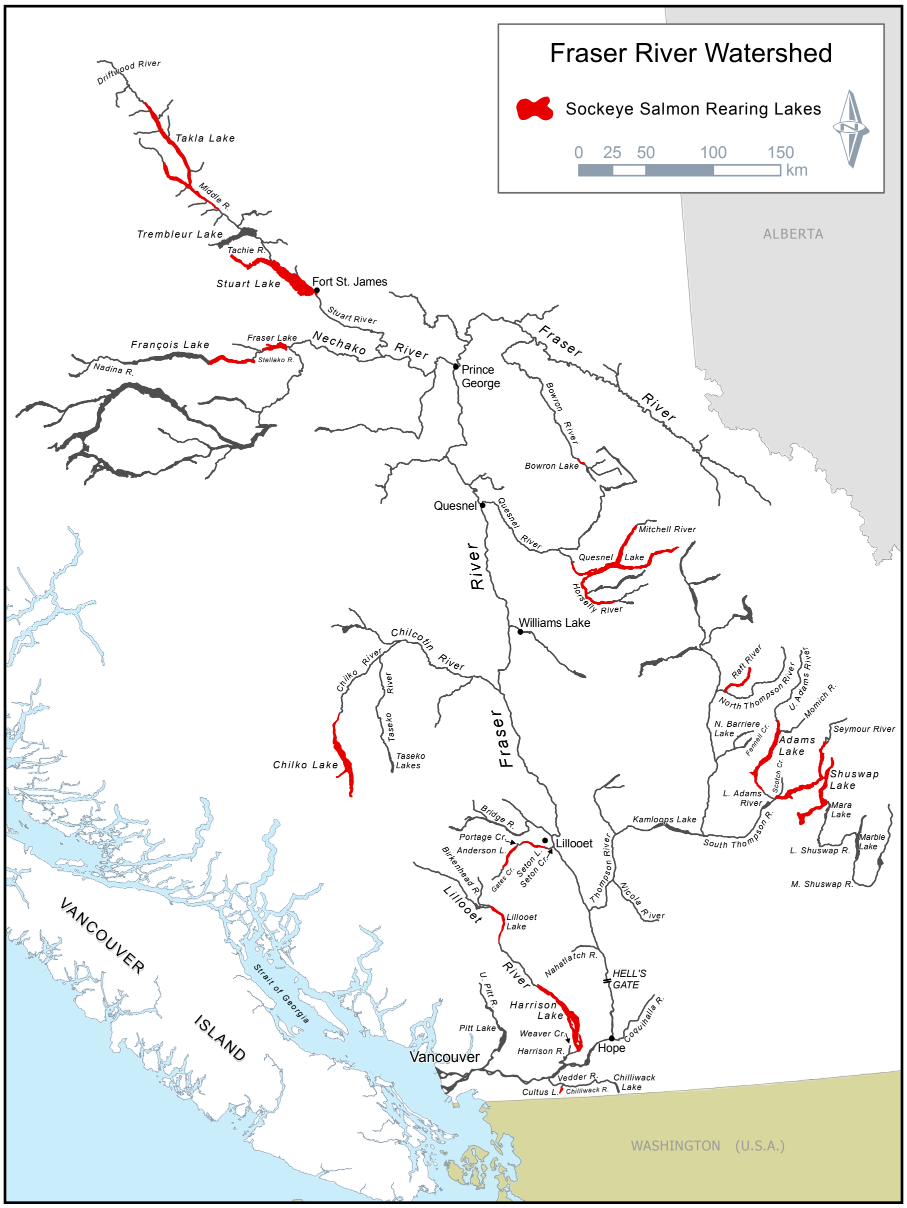

Figure 1.2.2 Fraser River sockeye salmon–rearing lakes

Source: Technical Report 4, Marine Ecology, p. 7 (reproduced from Exhibit 1291).

Mr. Lapointe testified that eight of these sockeye nursery lakes account for 80 percent of the juvenile-rearing capacity in the Fraser River watershed.[5] These nursery lakes are, in decreasing order of surface area, Stuart, Shuswap, Quesnel, François, Takla, Harrison, Chilko, and Adams lakes.[6]

The migration into these nursery lakes ranges between a few hundred metres and more than 100 km. The fry typically live in the lake for one year (May 2006–May 2007) or in some cases two years, feeding on zooplankton such as *Daphnia*. They tend to remain near the surface at dawn and dusk while feeding, and during the bright daylight hours they migrate deeper to avoid predators.

Mr. Lapointe said that the principal sources of mortality for fry are lack of food, predation, diseases, and environmental stressors such as water temperature.[7]

Smolts

By approximately May 2007, about 20 months after spawning, when the fry are about 8 cm long, they begin a process called "smoltification," a physiological change required for the transition from life in freshwater to life in seawater. They cease their movement between shallower and deeper parts of the lake; begin to gather into schools of fish; develop an ability called "compass orientation," which aids their navigation out of the lake and downstream; and take on a silvery body colouration.

The downstream migration to the ocean ranges widely, from 40 km for the Widgeon Slough population to 1,200 km for the Early Stuart population. One of the largest populations, resident in Chilko Lake, will reach the Strait of Georgia in about eight days. During this downstream migration, predation is a major source of smolt mortality.

Fraser River sockeye river-type populations, such as the Harrison River population, do not spend a year in a nursery lake and have a different outmigration pattern. They migrate downstream almost immediately after emerging from the gravel and, after spending a few months in sloughs and estuaries, enter the Strait of Georgia before they are one-year-old (2006).

Migration through the Strait of Georgia

After leaving the river, it is believed that most Fraser River sockeye juveniles turn north and migrate through the Strait of Georgia, Johnstone Strait, and Queen Charlotte Strait and into Queen Charlotte Sound. Dr. Welch said that, by late 2007, Fraser River sockeye were present throughout the northern British Columbia coast, the Alaska Panhandle, and the Alaska Peninsula.[8]

There is some evidence that the Harrison River population, and perhaps other populations, is an exception to this migratory pattern. For example, it appears that the Harrison River population spends the remainder of its outward migration year (2006) in the Strait of Georgia and then migrates south of Vancouver Island through Juan de Fuca Strait to the west coast of Vancouver Island.[9]

Continental shelf and Gulf of Alaska

On leaving the Strait of Georgia, juvenile sockeye (also called"postsmolts") continue their migration through Johnstone and Queen Charlotte straits toward the North Pacific Ocean, where they enter south of Haida Gwaii (Queen Charlotte Islands). On entering the North Pacific Ocean, there is some evidence that the postsmolts migrate north and westward within 35 km of the coasts of British Columbia and central Alaska until they reach the overwintering grounds south of Alaska during late autumn and early December. Figure 1.2.3 depicts the postsmolt migration along the continental shelf.

The distribution and movement of immature Fraser River sockeye salmon at sea is the least understood of the fish's life history phases. Dr. Welch testified that his recent research suggests postsmolts are staying resident on the continental shelf, as far west as the beginning of the Aleutian Islands, for many months. In his testimony, Dr. Welch commented on earlier studies:

> There was a conjectural model that was developed by French and colleagues some 40 years ago now on what the movements of sockeye were. This is … where science … meets art. It was the best guess that the biologists at the time could identify with

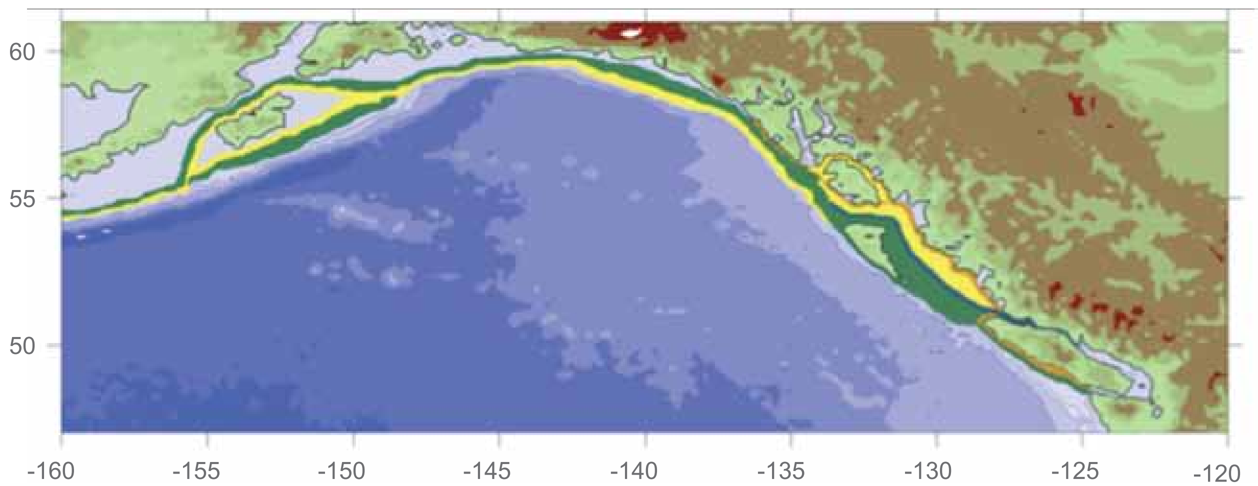

Figure 1.2.3 Seasonal migration of Fraser River sockeye salmon postsmolts after leaving the Strait of Georgia

Notes: Blue, May–June; green, July–August; yellow, October–November; orange, February–March.
Source: Technical Report 4, Marine Ecology, p. 17 (Exhibit 1291).

> the technologies at their hands and the data that they'd collected, and it shows a pattern of movement back and forth which Mike Lapointe has already indicated to you. My personal view on this is that it's simply the best guess we can make, but it's a lovely work of fiction that fits the very thin amounts of data that we have, but I don't think that it's necessarily appropriate or correct for Fraser River sockeye or possibly for any species of – any stock of sockeye salmon. I think they're doing something much more sophisticated than this, but the data is too simplistic to really tell you what Fraser River sockeye are doing.[10]

Stock-specific movements of Fraser River sockeye in the open ocean are unclear, but there is some evidence that, offshore, different sockeye stocks appear in different locations. Dr. Welch indicated that sockeye from the Nass, Skeena, Fraser, and Columbia rivers and from Rivers Inlet were spatially separated during the month of June.

Dr. Welch also testified that when sockeye salmon are small they eat plankton, but as they grow larger they eat other fish and squid. He referred to a 1992 study which showed that the abundance of both Gulf of Alaska plankton and pelagic fish and squid doubled in the 1980s (over the 1950s and 1960s), a period also marked by rapid increases in Fraser River sockeye.

Returning to the Fraser River

In their fourth (or, in some cases, fifth) year of life (2009), and after spending two (in some cases, three) years in the Gulf of Alaska, Fraser River sockeye leave the Gulf of Alaska and return to the Fraser River to spawn. Fraser River sockeye are captured in fisheries between Alaska and Washington State; their availability depends on their migration route. There are two migratory return routes – through Johnstone Strait and the Strait of Georgia (the northern diversion route), or down the west coast of Vancouver Island and through Juan de Fuca Strait. The percentage of sockeye salmon that follow the northern diversion route varies from year to year. Dr. Welch referred to a study showing that, when the ocean temperature is 10°C, the migration is almost entirely through Juan de Fuca Strait; but when the temperature increases to 12–13°C, 80–90 percent of returning sockeye come through the northern diversion route.[11]

Mr. English explained that, when returning Fraser River sockeye approach the coast in Alaska as opposed to farther south, a larger portion of the run tends to migrate through Johnstone Strait. This pattern is common for sockeye returning after mid-August and is particularly common in strong El Niño years, when there are warmer waters farther north in the Pacific Ocean. In contrast, when Fraser River sockeye approach the coast in southern British Columbia – especially sockeye returning in June, July, and early August – a larger portion of the run tends to migrate through Juan de Fuca Strait.

Fraser River sockeye coming south along the west coast of Vancouver Island continue to feed, and there is some evidence that salmon migrating south through the Strait of Georgia do so as well. However, once they begin their upstream migration, their digestive tract shuts down. Dr. Welch described the transformation that occurs:

> Sockeye store fat as oil in the muscles and as they migrate up the river, for example, they burn that oil or fat to fuel the migration and they replace it with water. So as they progress up the river, their shape doesn't change, but they replace fat, which is energy-rich, with water and they become softer.[12]

Timing of entry into the Fraser River

As returning Fraser River sockeye approach the mouth of the Fraser River, either through Juan de Fuca Strait or through Johnstone Strait, there is some variation respecting how promptly they move into the river and begin their upstream migration.

This variation is based on the four run-timing groups – Early Stuart, Early Summer, Summer, and Late-run. The Early Stuarts (which return in June and July) and the Early Summers and Summers (which return in July and August) enter the Fraser River with little or no delay – perhaps within one day. Thus, sockeye passing through Johnstone Strait need six or seven days to move through the Strait of Georgia, enter the river, and reach Mission. Fish returning through Juan de Fuca Strait need five or six days to reach Mission.

However, the Late-run timing group (which has historically returned in August–September) exhibits two distinctive types of behaviour. Since the 1990s, some parts of the run will enter the river with little or no delay, at the same time as the Summer timing group. The others, as Late-runs have always done, will delay their entry at the mouth of the Fraser River for 20–30 days, or longer in some years.

Factors that influence river-entry timing include fish maturity, tides, river flow, and water temperature. Over time, an increasing overlap of the different run-timing groups has been observed. Mr. English described the increasingly early appearance of the Late-run timing group at Mission from late August during the 1990s to late July in the 2000s.

River migration

Through the use of radio transmitters in fish and at monitoring locations along the Fraser River, it is possible to measure how quickly returning salmon move upriver and to assess their passage through challenging areas such as Hell's Gate canyon and the Bridge River rapids. Early Stuarts move the fastest – one fish, tagged at Mission, swam 800 km to the Stuart system in 16 days, averaging 45–50 km per day. A Summer-run sockeye, moving more slowly, took 24 days of freshwater migration to reach the Chilko system. During 2009, migration speeds of Summer-run sockeye ranged between 32 and 40 km per day.[13]

Water temperature plays an important role in survival. In the ocean, sockeye prefer temperatures of 12–14°C, or even cooler. However, as the fish migrate upstream, river water temperature is frequently between 18 and 20°C. There is some evidence that sockeye will interrupt their migration by remaining in cooler lakes for a week or longer to bring their temperature back down before pressing upstream to their spawning area. Research undertaken between 2002 and 2006 showed that Late-run sockeye entering the river before mid-August experienced a very low probability of survival, while those beginning their upstream migration in mid- to late September were far more likely to reach the spawning ground and actually spawn.[14]

Mr. Lapointe testified that Environment Canada records show that increasing water temperature in the Fraser River is a significant environmental change – eight of the 10 warmest summer river temperatures on record have occurred in the 15 years from 1996 to 2011.[15]

Life cycle survival

Significant mortality occurs throughout the various stages of the Fraser River sockeye life cycle. Based on Mr. Lapointe's materials, I understand the mortality to be approximately as follows, although there clearly are variations among the different populations.

Eggs per female	3,000
Egg-to-fry mortality rate (86 percent)	-2580
Survivors to fry stage	420
Fry-to-smolt mortality rate (71 percent)	-298
Survivors to smolt stage	122
Smolt-to-adult mortality rate (91 percent)	-110
Survivors to adult stage	12
Fishery harvest rate (70 percent)	-8
Fish remaining for spawning	**4**

The same information can be presented graphically, as set out in Figure 1.2.4.

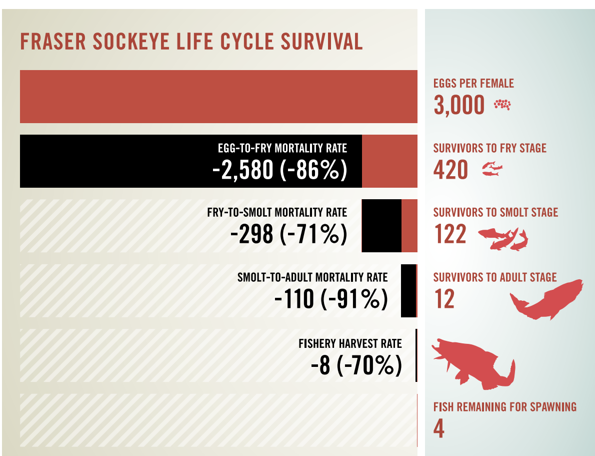

Figure 1.2.4 Fraser River sockeye salmon life cycle survival

Source: Compiled using data from Exhibit 1, slide 21.

Fraser River sockeye salmon migration – an enduring puzzle

In Technical Report 4, Marine Ecology, the authors divided the Fraser River sockeye salmon life cycle into 12 sequential habitats, represented in Figure 1.2.5.

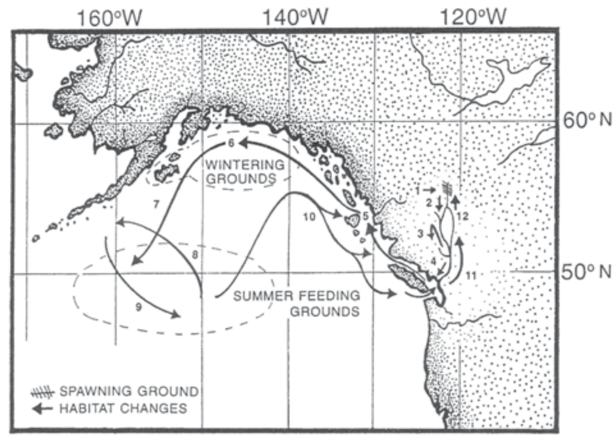

Figure 1.2.5 Habitats occupied by a typical Fraser River sockeye salmon

Source: Technical Report 4, Marine Ecology, p. 10 (Exhibit 1291).

The authors described each habitat as a bead in a chain linked by migrations. It is important that each habitat is in prime condition, and that migration routes between habitats are not hindered, blocked, or made unsuitable, because any weak or broken link will significantly affect production and survival. The authors added:

> The long distance migrations of sockeye salmon from habitat to habitat provide some of the most enduring puzzles in salmon ecology. The migrations are well timed and well directed and can vary from a few hundred metres to thousands of kilometres. To perform these feats, sockeye salmon possess a remarkable set of direction-finding mechanisms that include sun compass and magnetic compass orientation. They are also able to distinguish water masses, such as between their natal tributary and nearby tributaries, and differences between stocks on the basis of odour.
>
> Sockeye salmon are also able to migrate to a goal, such as the estuary of their natal stream, from any area in the North Pacific Ocean. This goal-finding ability is evident in the high rate of homing (greater than 95 percent) to their ancestral spawning grounds. To quote Ferris Neave, a fisheries biologist who worked at the

Pacific Biological Station for many years, "It is difficult to avoid the conclusion that throughout the period of ocean life some awareness of position in relation to the place of origin is maintained". The mechanisms underlying this capability are not well known.[16]

Notes

1 Exhibit 1291.
2 Exhibit 1915, p. 6.
3 Michael Lapointe, Transcript, October 25, 2010, p. 17.
4 Transcript, October 25, 2010, p. 18; Exhibit 1, p. 11.
5 Transcript, October 25, 2010, p. 29.
6 Exhibit 1, p. 37.
7 Transcript, October 25, 2010, p. 20.
8 Transcript, October 25, 2010, p. 35.
9 Exhibit 2.
10 Transcript, October 25, 2010, pp. 40–41.
11 Transcript, October 25, 2010, p. 42.
12 Transcript, October 25, 2010, p. 93.
13 Karl English, Transcript, October 25, 2010, p. 57.
14 Karl English, Transcript, October 25, 2010, pp. 59–61.
15 Transcript, October 25, 2010, p. 94.
16 Exhibit 1291, p. 10.