

The Ten Plagues and Statistical Science as a Way of Knowing

TAMMI BENJAMIN & MARC MANGEL

The Plagues

AS THE BIBLICAL ACCOUNT OF THE ISRAELITES' EXODUS from Egypt unfolds, the meanings of the "strong hand and outstretched arm" of God become manifest through the vehicle of the ten plagues: Blood fills the River Nile (Exodus 7:14–25); swarms of frogs invade every public and private place (Exodus 7:26–8:11); lice¹ infest man and beast (Exodus 8:12–15); insects² swarm upon the earth (Exodus 8:16–28); pestilence kills all of the Egyptian cattle (Exodus 9:1–7); boils cover man and beast (Exodus 9:8–12); a grievous hailstorm ravages the land (Exodus 9:17–35); dense hordes of locusts complete the destruction begun by the hail (Exodus 10:1–20); a darkness descends upon the land, so thick and foreboding it is palpable (10:21–23); and death strikes every firstborn Egyptian (Exodus 11; Exodus 12:29–33). However, as biblical commentators have pointed out, the plagues are more than just a divine strong-arm tactic for securing the release of the Hebrew people from their Egyptian bondage. Rashi cites the midrash in interpreting the plagues as having, first and foremost, a didactic purpose: coming to instill a knowledge of God in those who had been unwilling to acknowledge Him.³ Abravanel echoes this understanding, explaining that the plagues are a direct response to Pharaoh's initial rejection of Moses' plea to release the Hebrew people: "Who is Y-H-V-H that I should heed His voice to send out Israel? I do not know Y-H-V-H . . ." (Exodus 5:2).⁴

The text itself provides considerable support for the idea that the plagues are to convey a knowledge of God to all who witness them or hear about them. A transmission of God's existence and identity is one purpose of the plagues which God reveals to Moses before their onset:

TAMMI BENJAMIN is a lecturer in Hebrew in the Language Program of the University of California, Santa Cruz and a Jewish educator who specializes in Biblical Hebrew and the Hebrew Bible. She is director of education and principal of the Religious School at Congregation Kol Tefillah in Santa Cruz.

MARC MANGEL is Professor of Conservation Biology in the Department of Environmental Studies and Institute of Marine Sciences at the University of California, Santa Cruz. His research interests are focused on the ecological implications of life history variation. He has written *Decision and Control in Uncertain Resource Systems*, *Dynamic Modeling in Behavioral Ecology* (with Colin Clark), and *The Ecological Detective: Confronting Models with Data* (with Ray Hilborn).

And Egypt shall know that I am Y-H-V-H, when I stretch out my hand over Egypt. . . . (Exodus 7:5)

You shall say to [Pharaoh], “Y-H-V-H, the God of the Hebrews, has sent me to you, saying: Send out My people that they may serve Me in the wilderness—but behold, you have not heeded up to now.” So says Y-H-V-H, “*Through this shall you know that I am Y-H-V-H. . . .*” (Exodus 7:16–17)

Following the chronology of the narrative, the next four textual references to the purpose of the plagues allude to another kind of knowledge which the plagues are to convey, namely, an understanding of God’s nature. Specifically, and in turn, the plagues will reveal God’s uniqueness, immanence, might, and dominion:

For tomorrow . . . as you say—*so that you will know that there is none like Y-H-V-H, our God. . . .* (Exodus 8:6)

And on that day I shall set apart the land of Goshen upon which my people stands, that there shall be no swarm there; *so that you will know that I am Y-H-V-H in the midst of the land.* (Exodus 8:18)

For this time I shall send all My plagues against your heart, and upon your servants, and your people, *so that you shall know that there is none like Me in all the world.* For now I could have sent My hand and stricken you and your people with pestilence and you would have been obliterated from the earth. However, for this have I let you endure, *in order to show you My strength and so that My Name may be declared throughout the world.* (Exodus 9:14)

When I leave the city I shall spread out my hands to Y-H-V-H; the thunder will cease and the hail will no longer be, *so that you shall know that the earth is Y-H-V-H’s.* (Exodus 9:29)

The final two textual allusions to the plagues’ didactic function emphasize a third kind of knowledge that the plagues are to provide: knowledge of the special relationship between God and the Hebrew people and of its motivation of the course of events. In the first instance, this information is to be directed toward the Israelites themselves, and in the second toward Pharaoh:

Come to Pharaoh, for I have made his heart and the heart of his servants stubborn so that I can put these signs of Mine in his midst; and so that you may relate in the ears of your son and your son’s son that I made a mockery of Egypt and My signs that I placed among them—*that you may know that I am Y-H-V-H.* (Exodus 10:1–2)

But against the Children of Israel, no dog shall whet its tongue, against man nor beast, *so that you shall know that Y-H-V-H will have differentiated between Egypt and Israel.* (Exodus 11:7)

The text itself clearly indicates that the plagues’ purpose is, at least in part, a didactic one, and further alludes to the three kinds of knowledge that the plagues are intended to convey: a knowledge of God’s existence, God’s nature, and God’s motivation.

Within the Exodus narrative, the recipients of this knowledge are specified: Pharaoh, the Egyptians, the Israelites, and the nations of the world are all to learn about God from the plagues. However, if the narrative is viewed through the lens of literary analysis, Pharaoh, the Egyptians, the Israelites, and even God, are all merely characters in an artfully crafted story. Robert Alter argues that “the biblical authors are . . . constantly, urgently conscious of telling a story in order to reveal the imperative truth of God’s works in history and of Israel’s hopes and failings.”⁵ Within such a literary context, the reader or hearer of the story is not simply another recipient of the divine knowledge that the plagues convey; the reader/hearer is the primary target of this message: “The reality that the tale intends to convey is not past historical but present affective: the experience of events as they were taken in first by eye witnesses, then through the consciousness of the generations who perennially relived and reflected on them as the basis of their own living faith.”⁶

Transmission of Knowledge via the Plagues

If the plagues offer knowledge about God to those who read or hear about them, how is such knowledge transmitted? The obvious answer is that the awesome nature of each plague as it is described in the text provides sufficient empirical evidence for inducing a knowledge of God’s existence, might, and motivation. However, as Greta Hort has pointed out, all of the plagues but the last one can be accounted for by considering the vicissitudes of nature along the Nile Valley:⁷ red tropical earth, which during periods of heavy rainfall is discharged into the Nile, would give the appearance of the blood described in the first plague. The swarms of frogs of the second plague can be explained as a natural result of the flooding of the Nile, as can the mosquitoes (or lice), swarms of insects, cattle disease, and inflammation of the third through sixth plagues. The hailstorm of the seventh plague and the swarms of locusts of the eighth plague are both endemic to the Middle East. A dust storm could have caused the darkness of the ninth plague. Even the timing of these plagues and their differential effect on the Egyptians and Israelites can be accounted for as a chain of direct causal connections. Indeed, numerous phenomena such as these have been reported as occurring along the Nile Valley.⁸ Thus, natural explanations of the plagues such as those which Hort proposes make it difficult to conclude from the mere textual description of the plagues the existence, might, or motivation of God.

Nehama Leibowitz argues that it is often the text’s form rather than its content which carries its intended message: the Bible “imparts its teachings not by direct indoctrination, by a moral tagged on the story, but through the medium of the narrative, its structure and style and the organization of the plot.”⁹ She points out that even the earliest rabbinic commentators demonstrated their keen awareness of this in the enormous attention they paid to the finest details of literary structure such as repetition, juxtaposition, deletions and redundancies.¹⁰

From as early as Talmudic times, biblical commentators suggested that the plagues derive their ability to transmit a knowledge of God more from the way in which they are organized within the text than from their specific effects. Rashi notes:

There is a reason [given] in the Midrash in the case of each plague why this [particular one] and why that: God came against them with the tactics of warlike operations as carried out by kings in orderly sequence: a government (monarch) who is besieging a city first destroys its water supply, then they blow the trumpets and sound an alarm in order to terrify and dismay them—thus the frogs croaked and made a noise, etc., [their water supply having first been turned into blood]; just as you will find it stated in the Midrash of Rabbi Tanchuma.¹¹

According to this Midrashic interpretation, God becomes known by comparison to a conquering king. Each successive plague strengthens this analogy and the divine insight it provides.

Several ancient, medieval and modern authors point out that the ten plagues can be analyzed into three distinct sets. The earliest reference to this tripartite structure is found in the Passover Hagaddah: “These are the ten plagues which the Holy One, blessed be He, brought upon the Egyptians in Egypt, and they are as follows: Blood, Frogs, Lice, Wild Beasts, Pestilence, Boils, Hail, Locusts, Darkness, Slaying of the Firstborn. Rabbi Yehudah grouped them by their initials: Dezach, Adash, Beachab.”¹²

Rabbi Yehudah forms the three words that have become the traditional acronymic abbreviation of the ten plagues by combining the first letters of the Hebrew words for the first three plagues (Blood, Frogs, Lice) to create the first word, the first letters of the fourth, fifth and sixth plagues (Wild Beasts, Pestilence, Boils) for the second word and the first letters of the seventh through tenth plagues (Hail, Locusts, Darkness, Slaying of the Firstborn) for the third word.

Rabbi Joseph Albo and Don Isaac Abravanel both seek to discern the commonality of the plagues organized as Rabbi Yehudah suggests. According to Albo, each group of plagues comes to teach Pharaoh and the world about a different aspect of faith in God: the first set of plagues teaches about God’s existence, the second set about God’s providence, and the third set about the truth of prophecy.¹³ Abravanel concurs with Albo’s interpretation of the first two sets of plagues, but proposes that the third set comes to substantiate the principle that God can change the nature of things at will.¹⁴ Ravon points out that the first set of plagues involves water and land, the second set only land and the third set the air, suggesting that each set of plagues reveals a different area of God’s dominion.¹⁵

Other commentators note that the plagues can be divided into three distinct sets, but propose a slightly different division from that of Rabbi Yehudah. Each commentator analyzes the plagues into three sets of three plagues (Blood-Frogs-Lice; Wild Beasts-Pestilence-Boils; Hail-Locusts-Darkness) followed by a tenth plague wholly apart from the series (Slaying of the

Firstborn); and moreover, each commentator reveals literary patterns that can be discerned both within and across the three sets of plagues. Rashbam points out that the first and second plague within each set is preceded by a warning while the third is not.¹⁶ Bachya notes that the first plague of each set takes place at the river while the second plague of each set takes place at Pharaoh's palace.¹⁷ Cassuto demonstrates that before the first plague of each set God instructs Moses to confront Pharaoh "in the morning" and to "station" himself before Pharaoh; before the second plague in each set Moses' instructions are to "go to Pharaoh"; and Moses receives no instructions about how or when to approach Pharaoh before the third plague in each set.¹⁸

Various interpretations of this literary structure have been set forth. Malbim suggests that the third plague of each series, which is not preceded by a warning, comes as a punishment to Pharaoh for not heeding the warnings of the two previous plagues in the set.¹⁹ This interpretation emphasizes the idea that God is a just but exacting judge who offers opportunities for rehabilitation but imposes stiff sentences when those opportunities are spurned. Bachya comments that the river and palace, which provide the setting for the warnings of the first and second plagues in each set, are symbols of Pharaoh's power: Pharaoh regarded himself as master of the River, and the palace was understood to be the seat of his power. Thus the third plague in each set attests to the dominion of God over Pharaoh.²⁰ According to Nahum Sarna, a knowledge of God is conveyed not only through an understanding of the commonalities within and across these three sets of plagues, it is also conveyed by considering the very fact that such a textual structure can be found. Sarna argues that God is made manifest in the purposeful textual organization of what could otherwise be understood as random natural events.²¹

Although the interpretations of the different proposed structurings of the plagues are quite varied, each commentator seeks to articulate through his interpretation the knowledge of God which the plagues convey. Rashi and the rabbis of the Midrash find within the ordering of the plagues the understanding that God is like a conquering monarch, while Rabbi Yehudah and subsequent authors who propose a three-part organization of the plagues suggest that the structure can be analyzed to reveal different sets of divine qualities. When one considers each of these interpretations against the backdrop of the structure being interpreted, we see that the way in which commentators understand the plagues to be organized constrains to a significant extent the kind of analysis they impose upon the text in order to arrive at their interpretations. For Rashi and the rabbis of the Midrash, who understand the plagues to be organized according to the tactics of a conquering monarch, God comes to be known through the construction of an analogy. For those who propose a tripartite organization of the text, God comes to be known through the taxonomic process of classifying and describing the commonalities within and across the plague sets. Thus, in addition to transmitting a knowledge of God, each structure requires a specific methodology for determining that knowledge.

Parallel Series

We propose the existence of another organization of the plagues, which functions to further secure a knowledge of God in the mind of the reader or hearer of the story. This organization is expressed as two parallel series of plagues, one consisting of those plagues that are predicted (the first, second, fourth, fifth, seventh, eighth and tenth plagues), and the other consisting of those plagues that are not preceded by a forewarning or prediction (the third, sixth and ninth plagues).

Within the seven predicted plagues, there is a sequencing stratagem: the seven predictions that herald these plagues are cumulatively organized. That is, each successive prediction in the series demands, in addition to the proofs that have been required in previous predictions, a new kind of confirmational evidence. So, for example, while merely the effect of the first plague is predicted, both the effect of the second plague and its subsequent removal are predicted. And not only are the effect and subsequent removal of the fourth plague predicted, but so, too, how the plague will differentially affect the Egyptian and Israelite populations. In this way, the prediction of each plague in the series introduces the requirement for a new level of rigor and sophistication of the confirmational evidence, while the subsequent confirmation of each plague offers ever greater assurance that these events are not the random and unpredictable vagaries of nature.

Our analysis suggests the existence of seven predicted characteristics of the plagues, which are successively introduced and cumulatively required for the confirmation of each prediction: (1) the plague's effect, (2) its removal, (3) how it differentiates between Egyptian and Israelite, (4) its specific time of occurrence, (5) its degree of severity, (6) its uniqueness in history (i.e., that the event never happened before), and (7) the response of Pharaoh and his servants to the plague. The distribution within the text of the seven predicted plagues according to their predicted dimensions is shown in Table 1. Each column in this table corresponds to a different predicted plague, and each row corresponds to a different predicted characteristic of the plague. The entries are the locations in the Book of Exodus where the characteristics are predicted. Thus, for example, Exodus 7:17–18 contains the prediction of the plague of blood and its effect on the life in the Nile. Exodus 7:27–29 contains the prediction of the effect of the plague of frogs and Exodus 8:5–7 contains the prediction of the removal of the plague. The entries in Table 1 fill in the subsequent plagues, indicating the cumulative nature of the predictions.

The second set of three unpredicted plagues is also governed by an organizing principle whose function is to help ascertain that the plagues are the work of God's Hand. The third, sixth, and ninth plagues show in a sequential way the inferiority of Pharaoh's magicians and their magic to God and God's might. First, the magicians are humiliated by their inability to reproduce the third plague of lice (Exodus 8:14), despite their previous success in using their

magical powers and secret arts to replicate the first plague of blood (Exodus 7:22) and the second plague of frogs (Exodus 8:3). These same magicians and their powers are further denigrated in the almost comical description of the aftermath of the sixth plague. Not only are the magicians incapable of invoking the boils that have afflicted all of Egypt, but they are themselves so affected by the plague that they can not even stand before Moses (Exodus 9:11). According to ancient Egyptian belief, the magicians derived all of their magical powers directly from the gods, and no god was more powerful or important than Amon-Re, the sun-god.²² In the minds of the ancient Egyptians, then, the darkness of the ninth plague would have meant nothing short of the total eclipse of Amon-Re's powers, which would in turn have rendered the magicians utterly impotent and worthless in the eyes of their countrymen.

Once again we find that the text's form, when considered together with its content, yields a wealth of knowledge about God. In particular, this second series of unpredicted plagues, in its successive pitting of the powers of God against those of the magicians, provides compelling evidence for believing that it is God, and not the magicians or their magic, who is responsible for the awesome plagues.

Although the predicted and unpredicted series of plagues convey different information about God to the reader or hearer of the story, the organization of the plagues within both series derives from the same epistemological approach, which assumes that truths about God can be revealed by considering the weight of the accumulated evidence determined from careful analysis of the description of empirical phenomena. Within such an approach, each series of plagues provides necessary but not sufficient evidence for inferring that God's Hand is behind them : An analysis of the predicted plagues allows the reader to reject the possibility that the plagues are the result of random acts of nature, while an analysis of the unpredicted plagues leads the reader to accept that it is far more likely that God was behind the plagues than the magicians. Taken together, these two series act complementarily to eliminate nature and magic as possible sources of the plagues, leaving only God and God's might as the most probable explanation of these phenomena.

The Plagues and Modern Statistical Concepts

Our analysis of the predicted and unpredicted series of plagues suggests a remarkable correspondence between the epistemological approach underlying our proposed organization of the plagues, and the way in which data about the world is organized and analyzed within modern statistical and probabilistic methods. In particular, we find that notions underlying the two main lines of modern statistical reasoning, frequentist statistics and Bayesian statistics, are strikingly similar to the epistemological assumptions that underlie the predicted and unpredicted plagues, respectively. In order to illustrate this point, we describe each statistical theory, apply it to the data provided by the textual

description of one of the two series of plagues, and show that the theory fits the data in an exact way. It is important to emphasize here that we are not attempting to use statistics in order to prove either the veracity of the Bible's account of the plagues or their divine origin. Rather, our intention is to suggest a point of connection between one approach to understanding God that we have found in the ancient biblical text, and assumptions about how people come to know the world that were formalized and articulated within the framework of statistical science less than two centuries ago. In the concluding section of the paper, we seek to account for this extraordinary correspondence.

Science is the human quest to understand a natural world full of uncertainty. Indeed, it has been suggested that the uncertainty that characterizes the natural world is itself a prerequisite for the development of intelligence and the acquisition of knowledge:

If the conditions of life and the people themselves were entirely unchanging a definite organization would result, perfect in the sense that no one would be under an incentive to change. . . . With the introduction of uncertainty—the fact of ignorance and the necessity of acting upon opinion rather than knowledge—into this Eden-like situation, its character is completely changed. With uncertainty absent, man's energies are devoted altogether to doing things, and it is doubtful whether intelligence itself would exist in such a situation; in a world built so that perfect knowledge was theoretically possible, it seems likely that all organic readjustments would become mechanical, all organisms automata. With uncertainty present, doing things, the actual execution of activity, becomes in a real sense a secondary part of life; the primary problem or function is deciding what to do and how to do it.²³

Within the framework of scientific inquiry, if uncertainty motivates the quest for knowledge then statistics provides the means for harnessing that knowledge by accounting for the uncertainty in a formal, mathematical way. We can thus envision science as the competition between different descriptions of how the world works, with the competition arbitrated by data.²⁴ Statistics allows us to manage this competition in a logical and rigorous manner, drawing conclusions about a large number of events or the properties of a population from a sample of those events or from the population.

Frequentist statistics is based on the use of observed frequencies of different events to make inferences about the population or to test hypotheses. An essential tool of frequentist statistics is the null hypothesis: "Null hypotheses entertain the possibility that nothing has happened, that a process has not occurred, or that change has not been produced by a cause of interest. Null hypotheses are reference points against which alternatives should be contrasted."²⁵

That is, since it is often impossible to prove that something occurred, we construct a null hypothesis that is the complement of the hypothesis of interest, and use the accumulated data to assess the probability that the null hypothesis is true. As the probability that the null hypothesis is true decreases, it becomes

a less likely description of how the world works. At some point, the null hypothesis is considered to be disproved (and once disproved will remain that way) and is rejected; this leaves the original hypothesis. By convention and scientific tradition, the null hypothesis is rejected when the chance of observing the data, given that the null hypothesis were true, is less than 5%.²⁶ On the other hand, values as small as 0.1% have been proposed too;²⁷ indeed some scientists bemoan the establishment of arbitrary values for the rejection of the null hypothesis, but there is general agreement that establishing the 5% value has been beneficial for science since it allows a common standard for evaluating evidence.

Before discussing the plagues, we give an example of how null hypotheses are used and frequentist statistics proceeds. Imagine that you are handed a coin and are asked to determine if this coin is not fair, that is, if the probability of heads as the outcome of a single flip differs from the probability of tails as the outcome of a single flip. Clearly, one flip will not allow you to answer the question. Similarly, most of us would not reject the notion of it being a fair coin if two flips both turned up heads. But, suppose that 10 flips lead to 6 heads or 100 flips lead to 60 heads; is the coin fair? How do we interpret this information? To approach it from frequentist statistics, we construct the null hypothesis "The coin is fair" and then determine the probability of observing 60% or more heads as a function of the number of flips. Figure 1 shows the result of such a calculation. After only 10 flips there is about a 35% chance of observing 6 heads in 10 flips of a fair coin. However, given 100 flips, there is only about a 3% chance of observing 60 heads; if this were the datum, we would reject the null hypothesis that the coin is fair. Note that we have not proved that the coin is biased, only that if the coin were fair, the chance of observing the data is less than 5%.

In the context of the plagues, the objective is to determine if they are planned and non-random. The logical null hypothesis is then "The plagues are random events." Each of the seven predicted plagues has a pattern that makes the null hypothesis less likely. Furthermore, the constraints illustrated in Table 1 show that plagues are nested pieces of information, because each successive prediction in the series demands a new kind of confirmational evidence, so that evidence is added with each plague. In the context of statistical thinking we'd ask: "What is the probability that the Nile would turn red by natural means." After the probability of this prediction is assessed, we ask "What is the probability that both the effect of frogs and their removal can be caused by natural mechanisms," then "What is the probability that the effect and removal of insects, and the differential effects could be caused by natural mechanisms," etc. By the time the tenth plague is reached, the probability of the null hypothesis is so small that it is clearly rejected by the reader of the text. Note that this does not "prove" that God is behind the plagues. It only allows for the reasonable rejection of the hypothesis that states that the plagues were the result of random natural phenomena.

One of the compelling aspects of data arranged as in Table 1 is that it allows for far more rigorous statistical scrutiny than is possible with data consisting of single qualitative predictions. Thus, the descriptions of the predicted plagues present the reader/hearer with increasingly complex configurations of predictions which, when taken together, create a well articulated hypothesis that can be easily verified or rejected. Rosenzweig and Abramsky identified methods of this sort as being examples of a “dipswitch theory.” A dipswitch is a panel of switches, such as we usually encounter on the back of a computer, which need to be in the appropriate positions for the computer to work properly.

A dipswitch theory makes a bundle of articulated qualitative predictions. The more, the better. Perhaps any one of them could easily occur by chance. But finding that most or all of them do fit the data suggests that the model which produced them ought to be taken seriously as a working hypothesis. For example, Mittlebach et al. (1988) present and test a dipswitch theory of lacustrine population regulation. They make some 21 separate qualitative predictions and discover that only one of their models fits almost all of them. Chance alone can hardly account for such agreement.²⁸

Unlike the null hypothesis, which allows us to test the hypothesis of interest by eliminating all other possible hypotheses, the “dipswitch theory” plays its role in frequentist statistics by allowing us to confront a particular theoretical model with a complex configuration of data. In the case of the data presented in Table 1, only one model could fit the configuration of confirmed predictions: that the described events are planned and non-random. Once again, we have not proven that God is behind the planning and execution of the plagues, only that the plagues have indeed been planned and are therefore not random events.

In *Bayesian statistics*,²⁹ the probabilities of two or more explicitly stated competing hypotheses are evaluated using Bayes’s theorem.³⁰ The approach of Bayes’s theorem involves three components: (1) specification of particular hypotheses, (2) specification of prior probabilities that these hypotheses are true, and (3) a probability model that allows one to evaluate the likelihood of a set of observations, given each hypothesis. These components allow us to compute the posterior probability of a hypothesis, given the observations from the prior probabilities and the likelihood of the observations, given the hypothesis. For two hypotheses, the “odds ratio”³¹ measures the relative likelihood of hypothesis #2 in comparison to hypothesis #1, given the observations. As this ratio becomes more and more unbalanced (either approaches 0 or infinity), the posterior probability of one of the hypotheses approaches 0 and the other approaches 1. The hypothesis with posterior probability approaching 0 is rejected as untrue and the hypothesis with posterior probability approaching 1 is accepted as being true, within the context of the competition between these two hypotheses.

For example, imagine that one’s keys are lost and from past experience, they are either in the living room (which happens 80% of the time) or the

bedroom (which happens 20% of the time). Suppose that there is a 40% chance of finding them in each five minutes of search, regardless of the room. Common sense tells us that under these circumstances, we should start searching in the living room. However, common sense also tells us that at some point, if the keys are not found in the living room we should begin to search the bedroom. Bayes's theorem allows us to determine the probability that the keys are still in the living room, given that they have not yet been found. To do this, we form the two hypotheses that the keys are in the living room (hypothesis #1) or in the bedroom (hypothesis #2). In Figure 2, we show the posterior probability (panel a) and the odds ratio (panel b) as the search occurs. In panel a, the abscissa is the number of minutes that the living room has been searched and the ordinate is the posterior probability that the keys are still in the living room, given that they have not yet been found. Thus, for example, when the search commences the probability that the keys are in the living room is 80%. This drops to 3% after about 40 minutes of search and about .3% after about 50 minutes of search. In panel b, the ordinate is the odds ratio, which is the posterior probability that the keys are in the bedroom, divided by the posterior probability that the keys are in the living room. This starts at 1/4 (since the prior probabilities are 20% and 80% and their ratio is 1/4) but rises to more than 40 as the search continues. Thus, after 50 minutes of search, the odds that the keys are in the bedroom have shifted from 1:4 to about 40:1.

As we have previously suggested, in the case of the three unpredicted plagues, God and God's power is successively pitted against the magicians and their magic. From this contrast we can formulate two competing hypotheses that can be evaluated using Bayes's theorem: hypothesis #1 is that "The plagues were caused by the magicians and their magic," and hypothesis #2 is that "The plagues were caused by God and God's power." If we assume that the probability of the two hypotheses is approximately equal after the first two plagues, which both God and the magicians are capable of bringing about, it is clear that after the inability of the magicians to replicate the third plague the probability of hypothesis #1 ("magicians and their magic") diminishes, and the probability of hypothesis #2 ("God and God's power") increases. After the sixth plague, in which we see a further diminution of the magician's power, the posterior probability associated with hypothesis #1 decreases further, until finally it is essentially 0 after the defeat of both the magicians and the source of their magic in the ninth plague. Thus, the three unpredicted plagues provide a sequential movement toward a total rejection of the possibility that the plagues were caused by the magicians and their magic, and an acceptance of God's primary role in bringing about these events.

We also see that the two sets of plagues are complementary. The predicted ones effectively allow us to reject the null hypothesis that natural events caused them. The unpredicted plagues provide a specific confrontation between the two hypotheses concerning the Hebrew God and His power

versus the Egyptian magicians and their power, in which the posterior probability associated with the magicians is negligible.

The Relationship Between the Bible and Modern Statistical Science

We have presented evidence to suggest that the Ten Plagues described in the Book of Exodus have a didactic purpose which is to convey a knowledge of God to the reader or hearer of the story. The plagues' textual structure is an important transmitter of this information, and we have surveyed several previously proposed structures and summarized how biblical commentators throughout the ages have derived from them specific information about God. In addition, we have suggested that underlying each proposed organization of the plagues is a set of epistemological assumptions about *how* a knowledge of God is to be acquired.

Within this context, we have presented our own analysis of the literary structure of the Ten Plagues in which we identify two distinct series of plagues whose purpose is to provide confirmational evidence for postulating that God and God alone is behind the plagues. Through the cumulative organization of the predictions of the first series of seven predicted plagues, their non-random and unnatural quality is effectively proven. Through the sequencing of the three unpredicted plagues, the primacy of God and God's power over the magicians and their power is dramatically demonstrated. These two series thus act complementarily in showing that the plagues are neither the result of the random vagaries of nature nor a consequence of temporal magic, but are rather the awesome expression of God's will.

Moreover, we have characterized the epistemological approach underlying this organization as being one which assumes that a knowledge of God can be acquired by considering the weight of the evidence determined from a probabilistic analysis of the descriptive data. We have also found a correspondence between this epistemological approach and the approach towards knowing the world embodied in modern statistical science. In particular, the assumptions about how data are organized and analyzed, which underlie the predicted and unpredicted plagues, find formal mathematical expression in frequentist statistics and Bayesian statistics, respectively.

We believe that the similarity of the ideas underlying the textual organization of the Bible and modern statistical thinking is not coincidental. Rather, we hypothesize that it derives from the tremendous impact the Bible has had on western scientific thought, and we offer two ways in which the Bible may have made its influence felt in the modern world.

First, based on an understanding of the historically strong relationship between religion and science, it might be that the Bible has had a direct influence on the scientists working within the western scientific tradition. Although not so in our own day, for most of the time western universities have existed intellectuals were deeply connected to organized religion. It was only with the rise of statistical thinking in biology and physics in the mid-nineteenth

century (with the publications of Darwin and Maxwell)³² that a conflict between science and religion seemed apparent. However, this revolution can be interpreted more as an opposition of science and certain political structures than of science and religion,³³ thus suggesting that the interaction between science and religion that followed the statistical revolution may be deeper than usually portrayed. Our proposal is that biblical study was for so long a time part of western intellectual life that it implicitly defined much of the fundamental world view of individual scientists, often without their knowledge. This view of the Bible's power to influence the way in which individuals formulate their conceptions of the world was expressed two thousand years ago by the rabbis of the Mishna: "Turn [the Torah] and turn it, for everything is in it and through it you will perceive clearly. . . ." ³⁴

Thomas Bayes, the eighteenth-century English mathematician responsible for establishing the mathematical basis for probability inference embodied in Bayesian statistics, was a Nonconformist minister. It has been suggested that Bayes's mathematical work was significantly influenced by his theological ideas:

Not even one of [Bayes's] works on mathematics was published during his lifetime, but one of two posthumous works of his served to embed his name in what has become, two centuries after his death, one of the most widely known eponyms in all of science, Bayesian inference. . . . The origin of Bayes's "Essay" is a mystery. . . . Bayes's motive for taking up the question has been the cause of some speculation; some have even guessed that an attempt to provide a mathematical proof of the existence of a First Cause lay behind it.³⁵

Bayes's statistical formulations could well have been shaped by his study of the Bible and, in particular, by his understanding of the epistemological organization of the Ten Plagues.

In addition to the impact biblical study may have had on individual scientists, the Bible has had a less direct but nonetheless profoundly far-reaching influence on the development of scientific and statistical thinking. More than any other piece of literature, the Bible has influenced the history and culture of Western Civilization, insinuating its view of God, the universe, and humankind into the intellectual processes of the Western mind often without its impact being recognized:

Millions of modern people who do not think of themselves as religious live nevertheless with basic presuppositions that underlie the biblical literature. It would be impossible to calculate the effect of such presuppositions on the changing ideas and attitudes of Western people with regard to the nature and purpose of government, social institutions, and economic theories.³⁶

Moreover, as historians of science have noted, scientific thinking does not take place in a vacuum but is significantly influenced by the world view in any given culture at any period in its history: "[S]cience is not the mere collecting of facts—though that is necessary; it is a system of logical correlations of those facts

cementing together a hypothesis or body of theory. This theory is itself tempered by the general outlook of the times in which it is formulated."³⁷

Thus, to the extent that the Bible has influenced the way in which the Western mind thinks, it has also helped to shape scientific reasoning and the theories it has created in every era. Support for this view comes from an examination of the very different ways in which science has developed in cultures with vastly different oral or written religious traditions. For example, the significant differences between the development of Chinese and Western science have in part been attributed to differences in the way each civilization has understood the relationship between the universe and its creator.³⁸ We are therefore suggesting that over the centuries in which the Bible influenced Western intellectual life, the implicit structure of the plagues, which we have sought to make explicit through our analysis, became part of that intellectual life, influencing the development of statistical thinking about the world though scholars did not recognize its impact.

Although not readily apparent, there is an interesting corollary which derives from this proposed relationship of the Bible and the development of Western scientific thought, suggesting that there is a more reciprocal interaction between the two. Thus, while the textual structures which our analyses indicate clearly antedate by thousands of years the scientific developments to which they correspond, in each instance the textual analysis itself is only possible because of our current scientific understanding of the world. Applying this corollary to the case of our analysis of the Ten Plagues, we could infer that it was our very familiarity with modern statistical concepts such as frequentist and Bayesian statistics that allowed us first to find, and then to formalize, the epistemological structure of the text. We would similarly presume that the innovative structural analyses of the plagues that have been offered in previous eras are also the result of the application of contemporaneous advances in knowledge to an understanding of the Bible. For example, we would postulate that the previously cited Midrashic conception of the logical progression of the plagues as being analogous to the orderly sequence of warlike operations carried out by a conquering king was based upon the most current understanding of the principles of military science available in Talmudic times. Therefore, while we are proposing that the Bible has had a profound influence on the development of epistemological paradigms in every age within western civilization, we are at the same time suggesting that the textual structures which form the basis for these advances in knowledge are themselves only discernible once such knowledge has been formalized. Most stories can be told in different ways, but some ways of telling the story are only appropriate after a certain level of intellectual, moral or spiritual development has been reached. For example, Arthur Green has noted that a "new Creation story is emerging in our day" and that this new creation story need not be in opposition to the "old Creation tale that for so long nourished and sustained the West's sense of origins and self-understanding."³⁹ It might be that we are only now ready to

understand the newer story, which has lain dormant for millennia, waiting for its time to be recounted.

In light of the striking correspondences between how knowledge is structured in the Hebrew Bible and in modern scientific formulations, and considering the relationship between our modern scientific world view and our ability to analyze these structures, we propose that a reciprocal analysis of biblical and scientific scholarship could enormously benefit both fields of inquiry. One advantage of such an interdisciplinary endeavor would be to understand more fully the tremendous impact that the Bible has had on the way we perceive the world. Conversely, we believe that the collaboration of scientist and biblical scholar could have a transformative effect on the way in which the Bible is studied, by facilitating the exploration and appreciation of the profoundly sophisticated nature of this ancient text.⁴⁰

NOTES

1. The Hebrew *kinnim*, which is usually translated as “lice,” has also been translated as “mosquitoes,” “gnats,” “sand flies,” and “fleas.”
2. The Hebrew *ha'arov*, which is often translated as “insects,” has also been translated as “beetles” or “wild animals.”
3. In his comments on Exodus 7:17, Rashi cites Midrash Tanchuma, Shemot Rabbah 9, 8.
4. Nehama Leibowitz, *Studies in Shemot* (Jerusalem: Haomanim Press, 1981), pp. 171–172. All biblical translations are from *Tanakh: The Holy Scriptures* (Philadelphia: Jewish Publication Society, 5748/1988).
5. Robert Alter, *The Art of Biblical Narrative* (New York: Basic Books, 1981), p. 46.
6. M. Greenberg, *Exodus* (New York: Behrman House, 1969), p. 204.
7. G. Hort, “The Plagues of Egypt,” *Zeitschrift für die alttestamentliche Wissenschaft* 69 (1957): 84–103; 70 (1958): 48–59.
8. Blood in the Nile River and an eclipse of the sun are related in James B. Pritchard, ed., *Ancient Near Eastern Texts Relating to the Old Testament* (Princeton, NJ: Princeton University Press, 1968), pp. 441, 445; swarms of flies are described in W. G. Lambert and A. R. Millard, *Atra-Hasis, with the Sumerian Flood Story* by M. Civil (Oxford: Clarendon, 1969) pp. 98–101; swarms of locusts are reported in *Encyclopaedia Britannica* 6:293 and 12:177–178, as well as sandstorms that darken the landscape and can last for days 13:105. The plagues of blood, frogs, parasites, flies, and darkness are discussed in the context of a climate change hypothesis by Arie S. Issar in *Water Shall Flow from the Rock. Hydrogeology and Climate in the Lands of the Bible* (New York: Springer Verlag, 1990), especially see pp. 104ff.
9. Leibowitz, p. 12.
10. Leibowitz, p. 19.
11. From Rashi’s commentary on Exodus 8:17.
12. Rabbi Joseph Elias, *Artscroll Mesorah Series: The Passover Hagaddah* (Brooklyn: Mesorah Publications, Ltd., 1989), pp. 129–131.
13. Elias, pp. 132–133.
14. Leibowitz, p. 172.
15. Elias, p. 133.
16. Rashbam’s commentary to Exodus 7:26 is cited in Shelomoh Zalman Netter, ed., *Midraot Gedolot Sefer Shemot* (Jerusalem: Eshkol, 1965), p. 29.

17. Bachya's commentary to Exodus 10:1 is cited in Rabbi Nosson Scherman, *The Artscroll Series/ Stone Edition: The Chumash* (Brooklyn: Mesorah Publications, 1993), p. 327.
18. Umberto Cassuto, *A Commentary on the Book of Exodus* (Jerusalem: Magnes, 1967).
19. Scherman, p. 326.
20. Scherman, p. 327.
21. Nahum Sarna, *Exploring Exodus* (New York: Schocken Books, 1986), pp. 75–78.
22. Sarna, pp. 58, 79.
23. F. H. Knight. *Risk, Uncertainty and Profit*. (Chicago: University of Chicago Press, 1971), pp. 267–268.
24. R. Hilborn and M. Mangel, *The Ecological Detective: Confronting Models with Data* (Princeton, NJ: Princeton University Press, 1977). Also see R. Royall, *Statistical Evidence. A Likelihood Approach* (New York: Chapman and Hall, 1997).
25. D. R. Strong, Jr. "Null Hypotheses in Ecology," *Synthese* 43(1980): 271–285.
26. See S. M. Stigler, *The History of Statistics. The Measurement of Uncertainty Before 1900* (Cambridge, MA: Belknap Press of Harvard University Press, 1986) and P. L. Bernstein, *Against the Gods. The Remarkable Story of Risk*. (New York: John Wiley and Sons, 1996).
27. See Bernstein, 1996.
28. M. L. Rosenzweig and Z. Abramsky, "Two Gerbils of the Negev: A Long-Term Investigation of Optimal Habitat Selection and Its Consequences," *Evolutionary Ecology* 11 (1997): 733–756.
29. See J. Berger and D. A. Berry, "Statistical Analysis and the Illusion of Objectivity," *American Scientist* 76 (1988): 159–165; C. Howson and P. Urbach, "Bayesian Reasoning in Science," *Nature* 350 (1989): 371–374; and C. Howson and P. Urbach, *Scientific Reasoning: The Bayesian Approach* (La Salle: Open Court Press, 1991).
30. Howson and Urbach, 1989, 1991 and R. Hilborn and M. Mangel, *The Ecological Detective: Confronting Models with Data* (Princeton, NJ: Princeton University Press, 1997).
31. Howson and Urbach, 1989.
32. See D. Simberloff. "A Succession of Paradigms in Ecology: Essentialism to Materialism and Probabilism," *Synthese* 43 (1980): 3–39.
33. J. Desmond and A. Moore, *Darwin. A Tormented Evolutionist* (New York: Time Warner Books, 1991).
34. Chapter 5 Mishna 26, from Reuven P. Bulka, *Chapters of the Sages* (Northvale, NJ: Jason Aronson Inc., 1993) p. 231
35. S. M. Stigler, *The History of Statistics*, p. 97
36. *The New Encyclopaedia Britannica*, 1991, 14:756
37. Colin A. Ronan. *Science: Its History and Development Among the World's Cultures* (New York: Facts On File Publications. 1982), p. 10
38. Ronan, p. 133
39. A. Green, *Seek My Face, Speak My Name* (New York: Jason Aronson, 1992), p. 54
40. For comments on various versions of the manuscript, we thank Murray Baumgarten, Nick Gotelli, Gail Hershatter, Mike Rosenzweig, and Gideon Rappaport.

Table 1: The Distribution in the Book of Exodus of Predicted Plagues by Prediction Dimension

Prediction Dimension	Plagues						
	1 Blood	2 Frogs	4 Insects	5 Cattle Disease	7 Hail	8 Locusts	10 Death of Firstborn
Effect	7:17-18	7:27-29	8:17	9:3	9:18	10:4-6	11:5
Removal		8:5-7	8:25	NA	9:29	10:17-19	NA
Differential Effects			8:18-19	9:4	(9:26)	(10:14)	11:7
Specific Time				9:5	9:18	10:4	11:4
Severity					9:18	10:5	11:6
Uniqueness						10:6	11:6
Egyptians' Response							11:8

NA - Prediction dimension of removal is not applicable to those plagues which are irreversible.

() - Parenthetical citations indicate that while the differential effects of these plagues are not predicted, they are evident after the plague has occurred.

Probability of observing more than 60% heads if the coin is fair

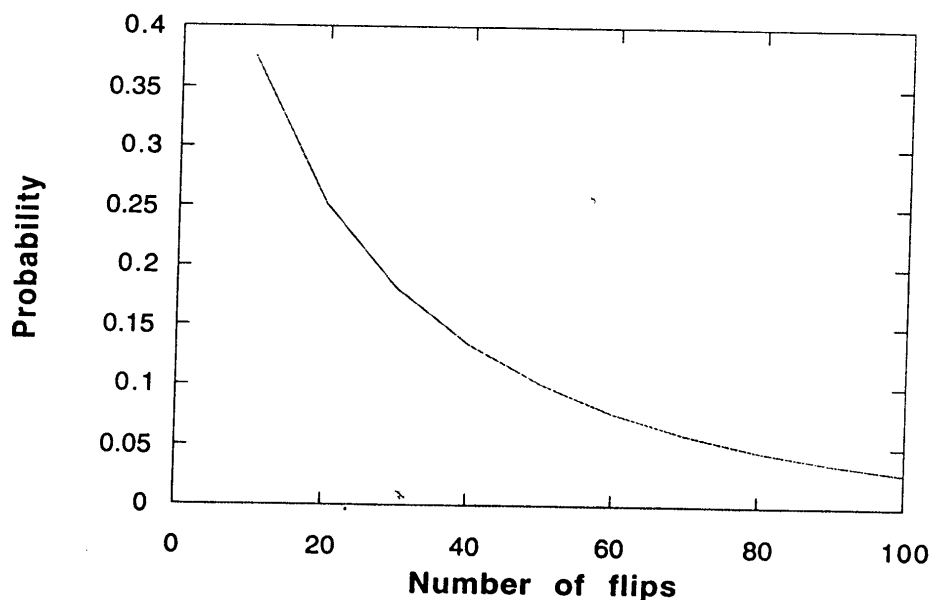


Figure 1. The abscissa shows the number of flips of a coin and the ordinate shows the probability of observing more than 60% heads if the coin were a fair coin. Thus, for example, there is about a 35% chance of observing 6 heads in 10 flips of a fair coin, about a 10% chance of observing 30 heads in 50 flips of a fair coin but only about a 3% chance of observing 60 heads in 100 flips of a fair coin.

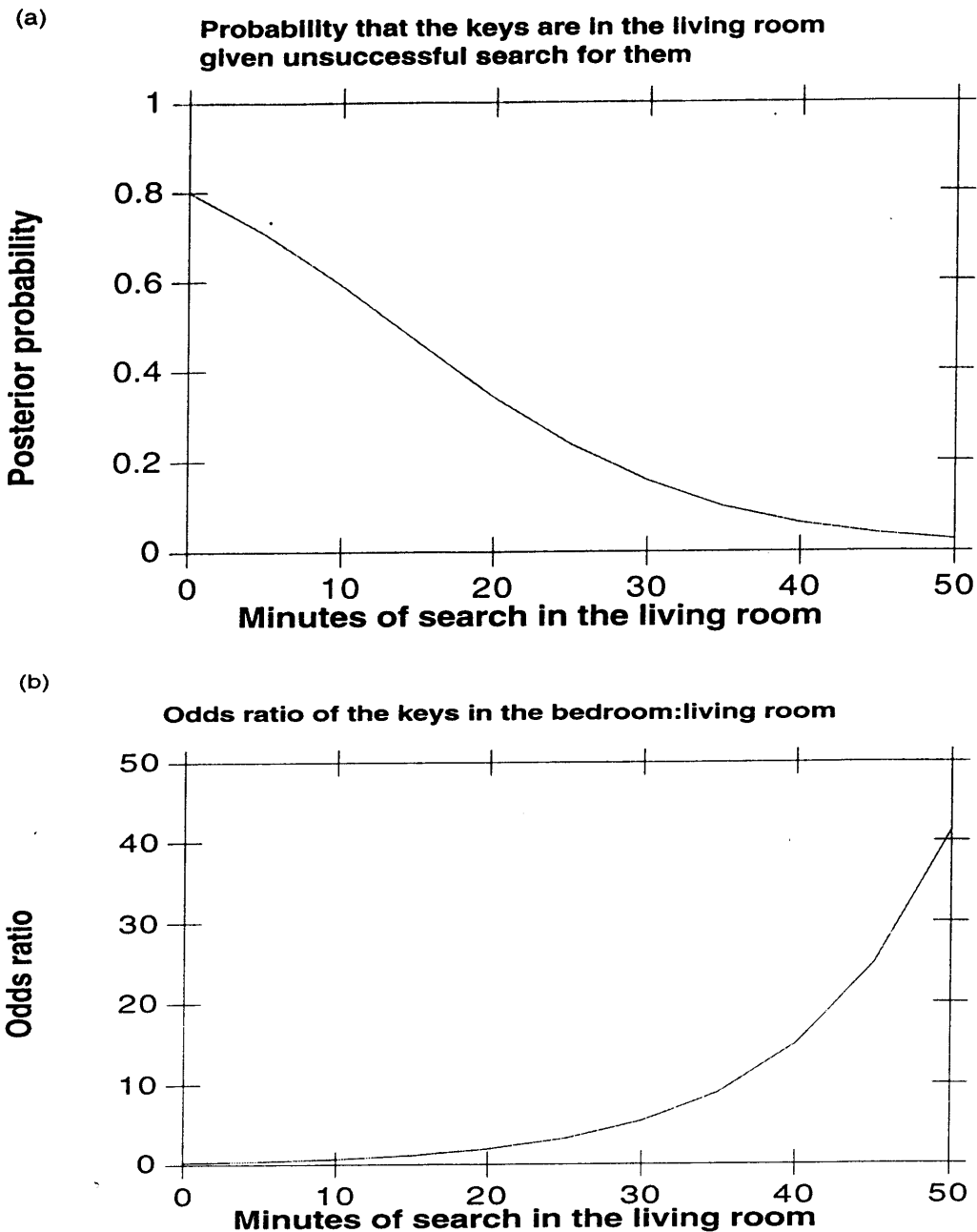


Figure 2. A Bayesian analysis of search for keys that can either be in the living room or dining room provides information on the posterior probability that the keys are in the living room, given unsuccessful search. In panel a, the abscissa is the number of minutes that the living room has been searched and the ordinate is the posterior probability that the keys are still in the living room, given that they have not yet been found. Thus, for example, when the search commences the probability that the keys are in the living room is 80%. This drops to 3% after about 40 minutes of search and .3% after about 50 minutes of search. In panel b, the ordinate is the odds ratio, which is the posterior probability that the keys are in the bedroom divided by the posterior probability that the keys are in the living room. This starts at .25 (since the prior probabilities are 20% and 80%) but rises to more than 40 as search continues. Thus, after 50 minutes of search, the odds are about 40:1 that the keys are in the bedroom.